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Planers, Shapers, and Milling Machines

273 ILLUSTRATIONS

By

EDITORIAL STAFF

INTERNATIONAL CORRESPONDENCE SCHOOLS

PLANER WORK
SHAPER AND SLOTTER WORK
MILLING-MACHINE WORK

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PLANER WORK
(PART 1)

PLANER CONSTRUCTION

PLANER DETAILS AND DRIVING

PARTS OF PLANER

1. Construction of Planer.—The planer is a machine used to produce flat surfaces on work. The work is firmly fixed on a table that moves to and fro under the cutting tool, and the tool is fed across the work in a direction at right angles to that in which the table moves. The advantages of the planer over other machines for making flat surfaces are that it is stiffer and will handle larger work. The planed surface is more easily scraped to a bearing or polished because the tool marks are parallel and continuous.

2. The planer illustrated in Fig. 1 shows the principal parts of the machine in their relation to one another. The table *a*, sometimes called the *platen*, has on its under side two **V**'s that run lengthwise and that fit in corresponding grooves or ways *b* in the heavy bed *c*. In heavy planers, one **V** way is used, in addition to one or two flat ways. The table has a rack on its under side meshing with a large driving gear called the *bull wheel*, and as this wheel is driven first in one direction and then in the other, the table is moved to and fro on the bed. The bull wheel is driven from the pulleys *d*, which are turned by two belts leading from the countershaft. The belts run in opposite directions, and pass through the slots in the arms *f* by which

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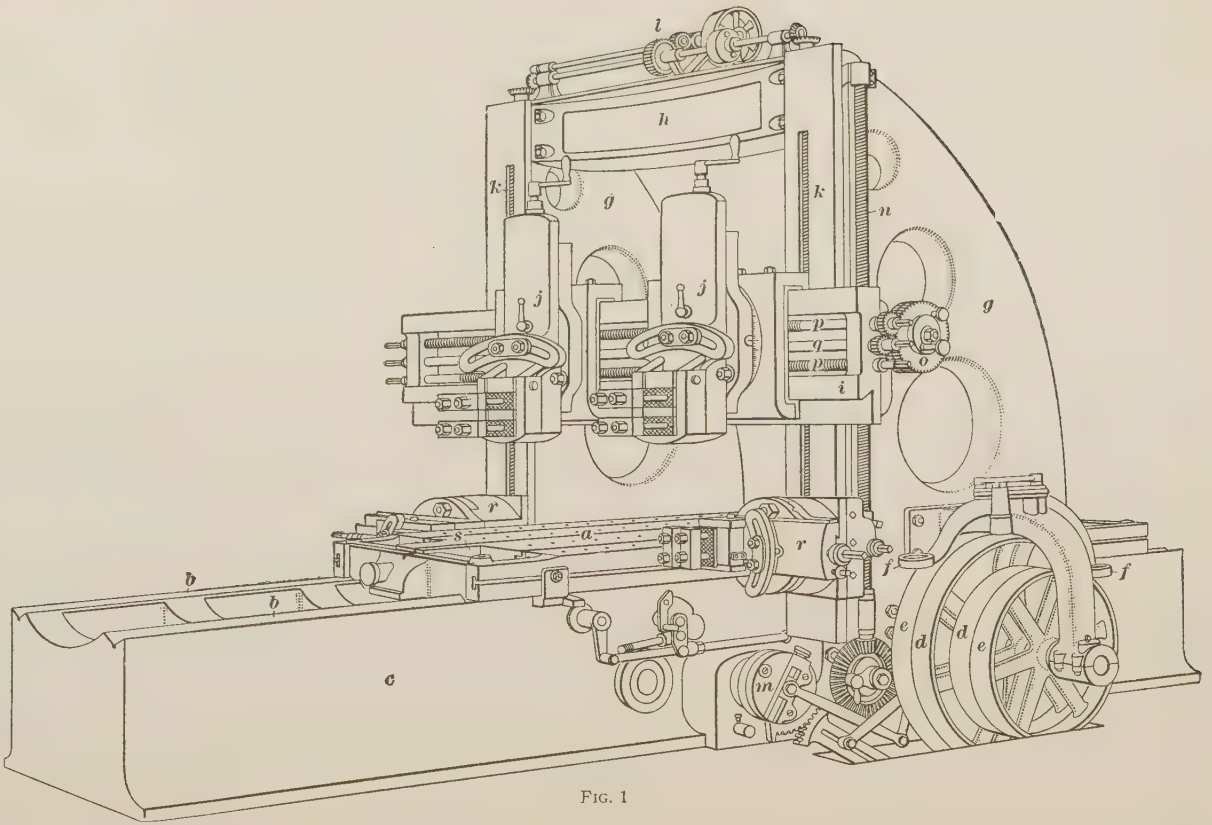

FIG. 1

they are shifted from the tight pulleys *d* to the loose pulleys *e*, or in the opposite direction, at the end of each stroke of the table. The table has several lengthwise slots in it and numerous holes drilled through it, so that the work may be clamped to the table easily and quickly.

3. On opposite sides of the bed *c*, Fig. 1, are bolted the heavy uprights, or housings, *g*, which are braced at the top by the arch *h*. In small planers the housings are bolted and keyed to the top of the bed, but in large planers they are bolted to the sides of the bed, also. The front faces of the housings are finished and against them is fitted the cross-rail *i* that carries the planer heads *j*. The cross-rail is raised and lowered by turning the two elevating screws *k*, the motion being given by the gearing *l* on the top of the arch. On the smaller sizes of planers, the cross-rail may be raised or lowered by hand. The planer heads *j* carry the cutting tools, which may be fed downwards or crosswise as the work is moved to and fro beneath them by the table. The feed-friction *m* gives motion, through a rod and a gear segment, to a vertical rack just behind the screw *n*, and the rack drives a pinion on the same shaft as the trigger gear *o*. Motion is thus given to the feed-screws *p* by which the heads *j* are moved sidewise along the cross-rail, and to the feed-rod *q* that may be used to move the tool vertically. The ends of the rods *p* and *q* are squared to receive cranks by which they may be turned by hand.

4. In the planer shown in Fig. 1, a side head *r* is placed on each housing. These side heads are similar to the heads on the cross-rail, and may be moved up or down along the faces of the housings; also, the tools carried by them may be fed horizontally across the work on the table. On small planers only one head is used, but on those for work 30 inches or more in width it is usual to fit two heads to the cross-rail. Large planers generally have two side heads in addition to the two heads on the cross-rail. The side heads are used when planing the sides of a piece of work at the same time that the heads on the cross-rail are used for planing the top surface; also, they are used for making special undercuts. For some special

classes of work, more than two heads are used on the cross-rail. In order to be supported during the whole length of the stroke, the table should not be more than half the length of the bed; but in practice the table is not always used at full stroke, and to increase the capacity of the planer, it is made about three-fifths the length of the bed. The pockets *s* at the ends of the table are intended to catch oil and chips. The planer shown in the illustration was chosen because it shows clearly many important features, but there are a great many other types, differing from this one in arrangement.

5. Planer Head.—Views of the planer head are shown in Fig. 2, together with a part of the cross-rail on which it is mounted. In (*a*) is shown a front view, in (*b*) an end view, and in (*c*) a view of the back of the saddle *a* when removed from the cross-rail *b*. The saddle is dovetailed along its back and is moved along the cross-rail by the screw *c*. This screw passes through a nut *d* fixed to the saddle, so that, when it is turned, the saddle is moved. On the front of the saddle the swivel plate, or harp, *e* is mounted, and it is so attached that it may be swung to one side or the other, thus inclining the tool at an angle, for planing bevels. By means of the bolts *f* it may be clamped tightly to the saddle. Gibs *g* are inserted between the saddle and the upper edges of the cross-rail, and a binding screw *h* is provided to clamp the saddle to the cross-rail. The slide *i* is carried by the swivel plate and may be moved up or down by turning the handle *j* on the screw *k*; it is locked in position by the binding bolt *l*. At the lower end of the slide *i*, the apron box *m* is swiveled, so that it may be swung to either side, thus allowing the tool to swing away from the side surface of the work being planed, on the return stroke of the table. It is slotted at the top, to allow it to be swung, and it may be clamped in the desired position by the bolts *n*.

6. The tool block *o*, Fig. 2, also called the apron, or the clapper, swings on a pin *p* that passes through the sides of the apron box. In small planers, the tool block usually carries a tool post with a screw to keep the tool in place; but in large planers it carries one or more clamps *q* in which the tool is held.

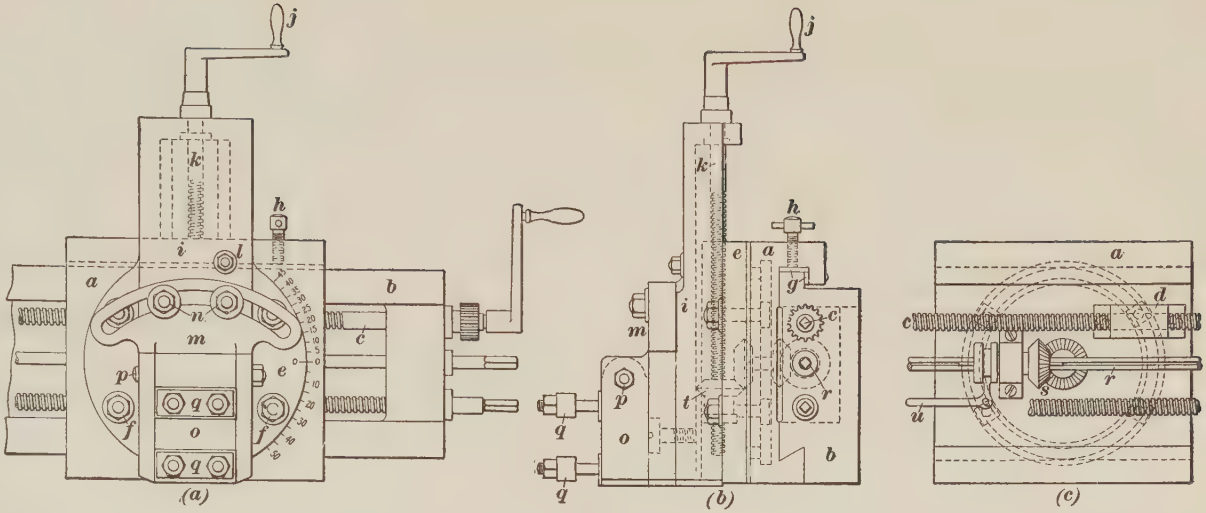

FIG. 2

The tool block bears solidly against the apron box during the cutting stroke, but swings outwards and upwards on the pin p during the return stroke. The tool is held firmly against a checkered plate that prevents it from slipping. The down-feed motion of the screw k is obtained from the feed-rod r through the bevel gearing s and t. The bevel gear at t forms a nut that fits over the screw k and is held in the swivel plate e, so that, when it is turned by the turning of the shaft r, the slide i is moved up or down. The down-feed motion is thrown into or out of action by moving the lever u.

7. Graduation of Planer Head.—In order to show how far from its central position the swivel plate is turned, its edge is marked with a series of graduations denoting degrees; or, if the swivel plate is not graduated, the graduations are marked on the face of the saddle, at the edge of the swivel plate, as shown in Fig. 2 (*a*). By means of these graduations, the head may be set at any desired angle to the work. Two ways of marking the graduations are shown in Fig. 3. In (*a*) the zero mark on the saddle *a* is opposite the 90° mark on the swivel plate *b* when the latter is in its central position, and the graduations run from 90° toward zero on each side of the 90° mark. In (*b*) the graduation corresponding to the zero on the saddle *a* is marked 0, and the graduations extend in each direction on the swivel plate. Side heads are graduated in the same ways.

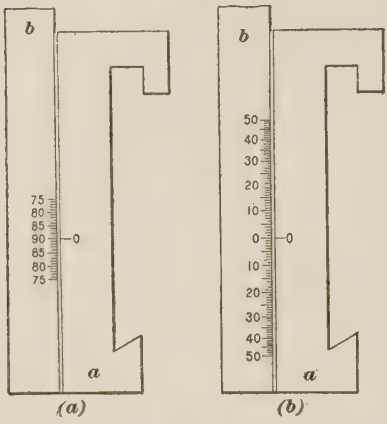

FIG. 3

8. Stating Size of Planer.—The size of a planer is given by stating the width, height, and length of the largest piece that can be planed on its table. Thus, a 48″×36″×10′ planer is one that will allow a piece of work 48 inches wide and 36 inches high to pass between the housings beneath the cross-

rail, and that will plane a piece 10 feet long on its table. The numbers are always stated in the order mentioned; that is, the width is given first, the height next, and the length last.

METHODS OF DRIVING PLANERS

9. Spur-Geared Planer.—Planers are driven in a number of ways. The gearing of a spur-geared planer is shown in Fig. 4. The shafts *a*, *b*, and *c* are carried by the bed and are at right angles to the direction of motion of the table *d*. The shaft *a* projects outside the bed and carries the driving pulleys *e* and *f* and the loose pulleys *g* and *h*. The two latter pulleys are free to turn on the shaft *a*. A small gear-wheel, or pinion, *i* on the end of the shaft *a* gears with the large wheel *j* on the shaft *b*, and a second pinion *k* on the shaft *b* drives the bull wheel *l* that gives motion to the table by driving the rack *m*. When the crossed belt *n* is running in the direction of the arrow *o* and driving the tight pulley *e*, the table *d* will be moved toward the right, on its cutting stroke. At this time the open belt *p* is running on the loose pulley *h*. When the table reaches the end of its stroke, both belts are shifted, the belt *n* being moved to the

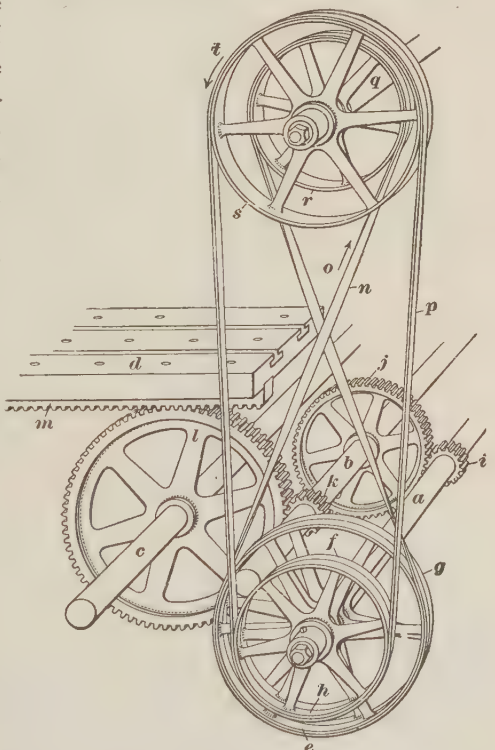

FIG. 4

loose pulley g and the belt p to the tight pulley f. As the pulley f turns in the opposite direction from the pulley e, the table is moved in the opposite direction on its return stroke. To prevent wear and noise in shifting the belts, the motion is so timed that one belt is removed from its tight pulley before the other is moved on its tight pulley.

10. Screw-Geared Planer.—The screw drive is found on some old styles of planers. A screw of large diameter

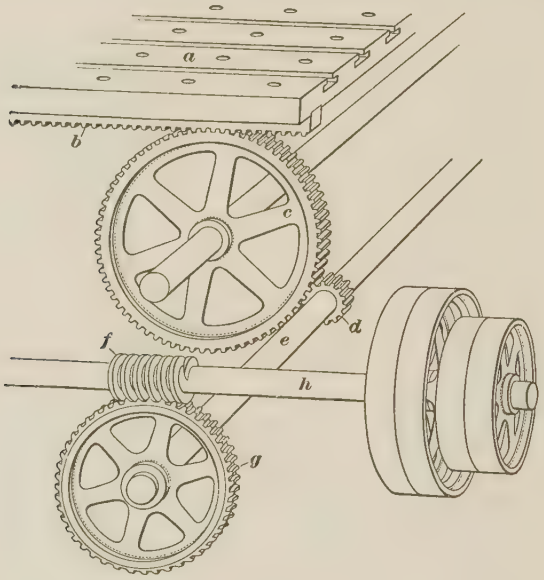

FIG. 5

extends the full length of the planer, under the table and midway between the V's, and engages with a nut that is fixed to the under side of the table. The screw is driven by suitable gearing at one end, and when it rotates the table is moved.

11. Worm-Geared Planers.—The gearing of a worm-geared planer is shown in Fig. 5. The table a has a rack b engaging with the bull wheel c, and the bull wheel is driven by the pinion d on the shaft e. On the outer end of this shaft is a worm-wheel g that is driven by the worm f on the same shaft h

with the tight and loose pulleys. The motion given by belt to the shaft *h* is transmitted through the worm and the worm-wheel to the bull wheel and the table. As the main shaft *h* is parallel to the line of motion of the table, this planer is also said to be parallel-driven.

12. Spiral-Geared Planer.—A top view of a spiral-geared planer with the housings and sections of the table and bed broken away is shown in Fig. 6. The shaft on which the belt pulleys are carried has at one end a bevel pinion *a* that gears with the bevel wheel *b* on the diagonal shaft *c* that extends

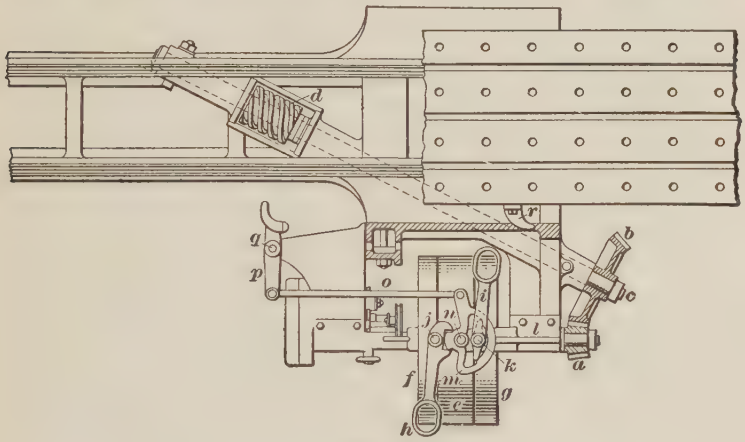

FIG. 6

through the bed beneath the table. The worm *d* is fixed on the shaft *c* directly under the center of the table and meshes with a rack on the under side of the table. The threads on the worm are cut spirally and slant at an angle to the shaft on which the worm is fixed. The shaft is therefore set diagonally in the bed, so that the worm threads at the points where they engage with the rack are at right angles to the line of motion of the table. When the worm is turned, a direct pull or thrust is put on the rack, thus moving the table. A very steady motion is given to the table by this style of gearing, which for some purposes is much more satisfactory than spur gearing; also, it is much quieter in operation than spur gearing.

PLANER MOTIONS

13. Quick-Return Motion.—The planer cuts during the stroke in one direction only, and in order to save time it is desirable to reverse the table and get it back quickly, ready for the next cutting stroke. The quick-return motion is used, therefore, so that the return stroke will take only one-half or one-third as long as the cutting stroke. A rapid return stroke of the table may be obtained by the arrangement shown in Fig. 7. On the driving shaft *a* of the planer are the two loose pulleys *b* and *c* and the tight, or fast, pulley *d*, all of the same diameter. The countershaft *e* from which the planer is driven carries two pulleys *f* and *g*, the former being of the same diameter as the pulleys *b*, *c*, and *d*, and the latter twice as great in diameter. The pulley *g* drives the pulley *d* during the return stroke of the table, and then the belts are shifted so that the belt *h* runs on the loose pulley *b* and the belt *i* runs on the fast pulley *d*. The pulley *f* then drives the pulley *d* on the cutting stroke of the planer. As the pulley *g* is twice as large as the pulley *f*, it will drive the pulley *d* at twice the speed obtained when the pulley *f* is driving, and thus the speed of the return stroke will be twice that of the cutting stroke; or, expressed in another way, the return stroke of the planer table will be made in half the time required for the cutting stroke.

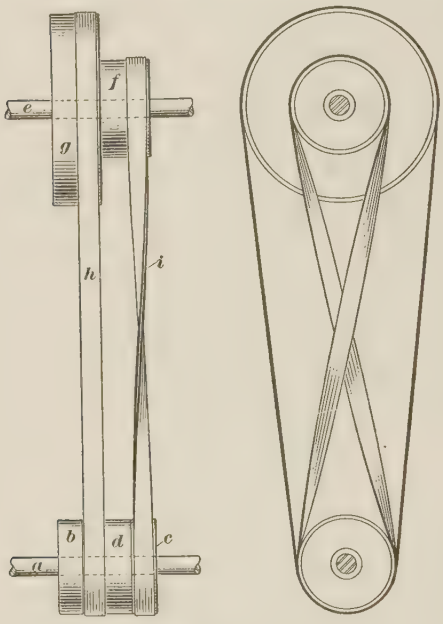

FIG. 7

14. Another quick-return motion is shown in Fig. 4. In this case there are two loose pulleys *g* and *h* and two tight pulleys *e* and *f* on the main shaft *a*. On the countershaft *q* are fixed the two pulleys *r* and *s*, both of which turn in the direction of the arrow *t*. The chief difference between this arrangement and that shown in Fig. 7 is that two tight pulleys *e* and *f*, Fig. 4, are required instead of a single wide pulley. The rapid return stroke is due to the fact that the pulley *f*, which drives the table on the return stroke, turns at a much greater speed than the pulley *e*, which drives on the cutting stroke.

15. Belt-Shifting Motion.—The planer-table motion is reversed by shifting one belt off a tight pulley on the main shaft of the planer and at the same time shifting the other belt on to a tight pulley. As the belts turn this main shaft in opposite directions, the motion is reversed every time they are shifted. A common method by which the shifting is done is shown in Fig. 6. In this case there is one broad tight pulley *e* and two narrow loose pulleys *f* and *g*. The belt to the pulley *f* passes through the opening at the end of the arm *h* and the belt to the pulley *g* passes through the end of the arm *i*. These arms are pivoted at *j* and *k* on pins attached to the bracket *l*, and each may be swung over the pulley *e* in turn by moving the arm *m* first in one direction and then in the other. The belts are thus alternately shifted to the tight pulley. The arm *m* is pivoted at *n* to the bracket *l* and is connected by a rod *o* to an arm *p* pivoted at *q*. There is a slot in the side of the table, in which two adjustable dogs are bolted, one of which is shown at *r*. These dogs are so placed that when the table has completed its required stroke in one direction, one dog strikes the curved end of the arm *p*, turns it on the pivot *q*, moves the rod *o* and the arm *m* and thus shifts the belts so as to reverse the motion. When the end of the required stroke in the other direction is reached, the other dog strikes the arm *p* and the belts are shifted in the opposite direction, again reversing the motion. The positions of these dogs therefore determine the length and position of the stroke.

16. Air-Clutch Reverse.—A view of an air-clutch reverse is shown in Fig. 8 (*a*) and a partial section in (*b*). This method

of reversing and driving the planer uses a double-faced clutch that is moved to one side or the other by air pressure and thus drives the planer slowly on the cutting stroke or rapidly on the return. It is an improvement on the forms already shown because all the driving is done by one belt and there are no

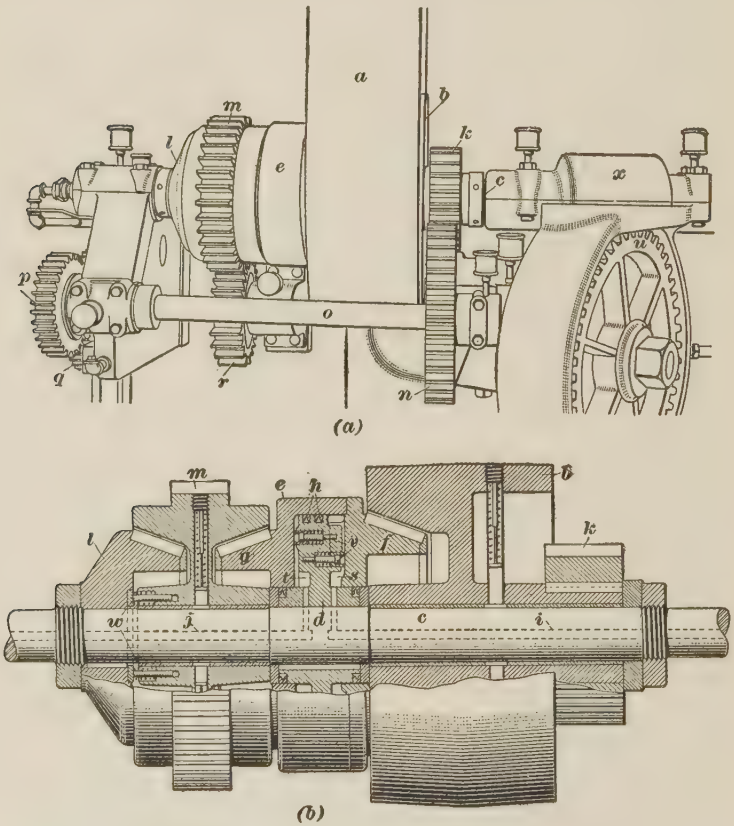

Fig. 8

pulleys to be stopped and reversed. Also, there are change gears by which the cutting speed may be altered to four different values, so as to suit the speed to the work being done. In the two views shown, similar parts are denoted by the same reference letters.

17. The single driving belt *a*, Fig. 8, runs on a wide pulley *b* that is loose on the shaft *c*. At the middle of the shaft is firmly keyed a piston *d*, over which fits a cylinder *e* that has two projecting conical faces *f* and *g*. The cylinder *e* is so fastened that it must turn with the piston *d* and the shaft *c*, but it may be moved slightly along the shaft in either direction. An air-tight joint is formed between the cylinder and the piston by the packing strips *h*. Two holes *i* and *j* lead from the ends of the shaft to opposite sides of the piston, through which air under pressure may be admitted. A small gear *k* is keyed to the hub of the pulley *b* and so must turn when the pulley turns. At the other end of the shaft a conical collar *l* is fastened, and between the collar *l* and the face *g* of the cylinder *e* is a gear *m* that is loose on the shaft *c* and that has two sloping inner faces corresponding to the faces of the parts next to it. The small gear *k* meshes with a larger gear *n* on the shaft *o* and this shaft at its other end carries a gear *p* that meshes with a similar gear *q* just behind it. The gear *q* is on one end of a short shaft that carries at its other end a gear *r* that meshes with the gear *m*. Thus, the gears *k* and *m* are connected through a series of gear-wheels.

18. The reversing is done by compressed air, which is admitted through pipes connected at the outer ends of the shaft *c*, Fig. 8. The flow of air is controlled by a valve that is moved by stops fixed to the planer table, and these stops are set so as to change the position of the valve each time the table reaches the end of a stroke. At the end of the cutting stroke the valve is moved so that air is admitted through the hole *i* in the shaft. It flows into the chamber *s* and the pressure it exerts forces the cylinder *e* to the right, causing the clutch *f* to engage with the pulley *b*. The pulley *b* then turns the cylinder with it, causing the shaft *c* to rotate. At the end of the shaft, inside the casing *x*, is a spiral gear that meshes with the gear *u* on a diagonal shaft by which the planer is driven. In this way the table is quickly returned. At the end of the return stroke, the valve is again moved, and the air is allowed to escape from the chamber *s*. At the same time air is admitted through the hole *j* to the space *t*,

causing the cylinder *e* to move to the left and gripping the gear *m* tightly between the clutches *g* and *l*. As the gear *m* receives its motion from the gear *k* through the gears *n*, *p*, *q*, and *r*, the shaft *c* is now rotated at a slower rate, and in the reverse direction, thus giving the table its cutting stroke. When no air pressure is acting, the cylinder *e* and the loose gear *m* are held in their central positions by springs *v* and *w*, thus preventing wear of the clutch surfaces.

19. Reversing by Electric Motor.—If the planer is driven by an electric motor that can run in either direction, then the reversing of the table may be done by arranging the motor so that it will be reversed at the end of each stroke. If a variable-speed motor is used, the different speeds on the cutting and return strokes may easily be obtained by arranging the motor to run at the desired speeds.

PLANER FEED-MECHANISM

20. Feed-Friction.—The feed-motion of the planer is usually obtained from the feed-friction, which is on the outer end of the shaft that carries the pinion that drives the bull wheel. The feed-friction and its connecting parts are shown in Fig. 9. It consists of an inner hub keyed to the shaft and surrounded by a friction band carried by the outer case *a*. Tension springs between the ends of the band hold it in contact with the hub, and when so held, the case *a* must turn with the hub and the shaft. Between the ends of the band is the squared end of the lever *b*, which is fulcrumed on a pin carried by the case *a* and extends outwards, as shown, between the stops *c* and *d*. The inner faces of the front and rear plates of the case are faced with leather that is held in sliding contact with the sides of the hub by three tension springs and bolts. As the shaft rotates in one direction, the grip of the band on the hub turns the case *a* through part of a revolution until the lever *b* strikes one of the stops. This causes the lever to swing on its fulcrum and its squared end then forces the ends of the band apart, releasing the grip of the band on the hub and thus stop-

ping the rotation of the case, which stops the feed. The leather facings now hold the case in its position until the table completes its travel. As soon as reversal occurs, the lever moves from the stop, the band grips the hub, and the case is turned in the opposite direction until the lever strikes the opposite stop.

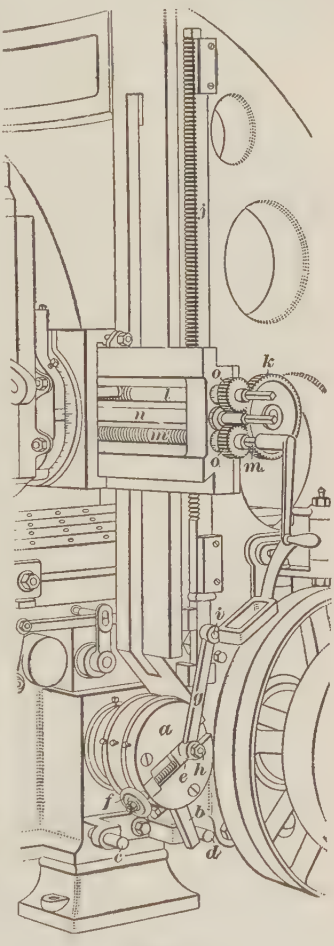

FIG. 9

21. In the outer face of the flange *a*, Fig. 9, is a long slot in which is an adjusting block *e* that may be moved in the slot by turning the wheel *f*. One end of the rod *g* is connected to a pin *h* on the block *e* and the other end to a pin *i* fixed in the lower end of the vertical feed-rack *j*. Therefore, as the flange *a* is turned to and fro by the gripping and loosening of the band fastened to the lever *b*, the pin *h* is swung up and down, and the rack *j* is moved up and down in the slides. The rack meshes with a pinion on the inner end of the shaft that carries the gear *k*, so that the gear *k* is rotated first in one direction and then in the other. By moving the block *e* farther from the center of the flange *a*, the movement of the rack and of the gear *k* is made greater. The motion of the gear *k* may be transmitted to the cross-feed screws *l* and *m* or to the feed-rod *n* by the trigger gears and ratchets shown at *o*.

22. Trigger Gear.—The trigger gear is simply a small gear and ratchet that is slipped on the end of the cross-feed

screw or the feed-rod to cause it to turn in only one direction. The gear *k*, Fig. 9, rotates first in one direction and then in the other, but the screws *l* and *m* or the rod *n* are to turn in only one direction. The construction of the trigger gear that enables this to be done is shown in Fig. 10, in which (*a*) is a view of the complete gear, and (*b*), (*c*), and (*d*) show the three main parts. The gear *a* is a ring having teeth on the outside and notches on the inner face. The body *b* slips into the gear *a* and is held by the collar *c*. There is a slot in the body *b*, in which is a pawl *d* that has two ends or wings *e* and *f*. This pawl is fixed on a short shaft *g* that has a handle *h* on the outer end.

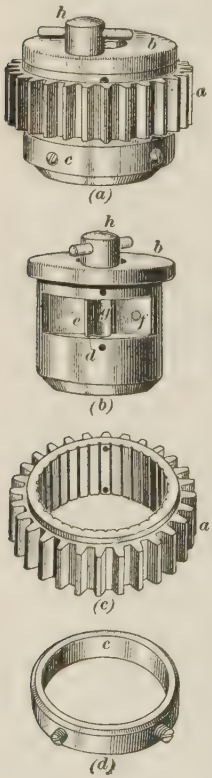

FIG. 10

23. The central part *b*, Fig. 10, of the trigger gear slips over the end of the cross-feed screw or the feed-rod, and the teeth of the gear *a* mesh with those of the gear *k*, Fig. 9. When the handle *h*, Fig. 10, is in the middle position shown, the ends *e* and *f* of the pawl do not extend beyond the slot, and when in this position the gear *a* would simply turn back and forth on the part *b*, when driven by the gear *k*, Fig. 9. By turning the handle *h*, Fig. 10, one of the ends of the pawl may be set out so that it will catch in the nicks or notches in the inner face of the gear *a*, when the latter rotates in one direction, but will slip over them when the gear rotates in the other direction. As there are two ends to the pawl, the gear may be made to drive the screw or the feed-rod in either direction. The feed-motion is stopped by simply turning the handle *h* until neither pawl engages with the gear.

24. Down Feed.—The down feed of the heads carried on the cross-rail is obtained from the feed-rod *n*, Fig. 9. The

trigger gears *o* are slipped off the ends of the screws *l* and *m* and one is slipped on the end of the feed-rod *n*, which is then driven by the gear *k*. This change of the gear *o* makes it impossible to throw in the cross-feed and the down feed at the same time. The feed-rod *n* is splined and turns a bevel gear in the back of the saddle. This bevel gear drives a second one that moves the down-feed screw, as explained in Art. **6.**

CUTTING SPEED OF PLANER

25. Conditions Affecting Cutting Speed.—The cutting speed of a planer must not be so high as to cause the tool to heat or to become dull very rapidly, and it should vary according to the metal being cut, the hardness of the metal, and the kind of cut being taken. Generally, the speed for a finishing cut is slower than for a roughing cut. The cutting speeds on various metals are about as follows: Cast iron, 20 to 50 feet per minute; steel castings and machinery steel, 20 to 35 feet per minute; wrought iron, 20 to 45 feet per minute; brass and bronze, 40 to 60 feet per minute; tool steel, 20 to 30 feet per minute. The use of high-speed steel tools has enabled the cutting speed to be increased greatly, but in most cases a speed of 55 feet per minute is about the greatest that can be used advantageously.

26. Finding Speed of Planer Table.—The speed of the table on the cutting stroke, or the cutting speed, may be found by the aid of a watch. The dogs are set so that the table makes its full stroke, and the length of this stroke, in feet, is measured. Then, by aid of the watch, the time required for the table to move this distance is found, in seconds. The cutting speed is then found by the following rule:

Rule.—*To find the cutting speed in feet per minute, divide the length of stroke of the table, in feet, by the number of seconds required to make the stroke, and multiply the quotient by 60.*

The return speed, or the speed of the table on the return stroke, may be found by the same rule, except that the time used must be the number of seconds required to make the return stroke. If a cut meter is at hand, it may be applied

directly to the top of the moving table and the speed on either stroke may thus be found at once.

EXAMPLE.—A planer table has a full stroke of 16 feet and requires 24 seconds to make the cutting stroke. What is the cutting speed?

SOLUTION.—Applying the rule, the cutting speed is

$$\frac{16}{24} \times 60 = 40 \text{ ft. per min.} \quad \text{Ans.}$$

VARIABLE-SPEED DEVICES

27. Changing Pulleys to Vary Speed.—If a planer has but one speed and it must be temporarily increased or decreased for some special class of work, a larger or smaller pulley is sometimes placed on the line shaft in place of the regular driving pulley. The regular pulley is meanwhile moved along on the shaft and secured. The change in the size of the pulleys also requires a difference in the length of the driving belt. The driven pulley on the countershaft is not changed. The *line shaft* is the main shaft from which power for operating a machine is taken. A *countershaft* is an intermediate shaft between the line shaft and the machine for determining the speed at which the machine will run and having a clutch or else tight and loose pulleys by use of which the machine is stopped or started.

28. Variable-Speed Countershaft.—Changing the speed of the table by changing the pulley on the countershaft is slow and inconvenient. A simpler and quicker way is to use a variable-speed countershaft, one form of which is shown in Fig. 11. The shaft a is driven at a constant speed from the line shaft and carries the pulley b and the cone pulley c. The pulley b drives the belt that gives the table its return stroke. A short shaft d parallel to the shaft a carries the cone pulley e, to one end of which is fastened the small pulley f. The pulley e is set so that its small end is in line with the large end of the pulley c, and a belt g connects these two pulleys. The slack in this belt is taken up by the roller h, which presses against the belt and so holds it to the pulleys. The pulley f drives the planer on its cutting stroke, and the speed of this stroke may be changed by moving the belt g. To increase the speed, the belt is moved

toward the larger end of the pulley *c*, and to decrease the speed it is moved in the other direction. The roller *h* is first raised by pulling the cord *i*, and then the cord *j* or the cord *k* is pulled, according as the speed is to be increased or decreased. The cords *j* and *k* are connected to the bar *l* carrying the fork that shifts the belt on the cone pulleys. After the belt has been shifted, the roller *h* is allowed to fall back into place. Four different cutting speeds may be obtained by using this device.

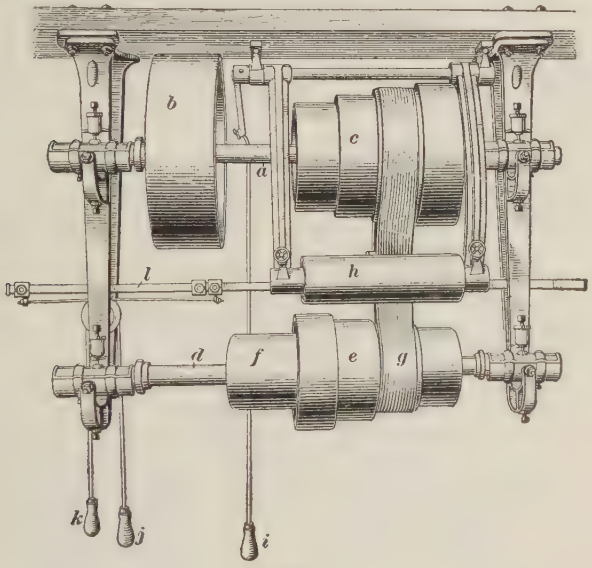

FIG. 11

Some makers supply a two-speed countershaft that gives two rates of cutting speed and a constant return speed.

29. Variable-Speed Gearing.—The cutting speed of a planer may be altered by the use of variable-speed gearing such as that shown in Fig. 12. The bull wheel *a* receives motion from the gear *b* through the gears on the intermediate shafts *c* and *d*. On the return stroke, the driving belt is on the small pulley *e* fast on the shaft *f*, and the gear *b* is thus driven direct. During the cutting stroke, the driving belt is on the pulley *g*, which is tight on the hub *h* to which the gear *i* is fixed,

but loose on the shaft *f*. The gear *i* drives the gear *j* fixed to the shaft *k*, on which are two pairs of gears *l*, *m* and *n*, *o*. These pairs of gears are arranged so that they may be moved along the shaft *k* by the shifting rods *p* and *q*, but must turn with the shaft. The four gears *r*, *s*, *t*, and *u* are keyed firmly on the shaft *f*. In the position shown, the gears *l* and *m* are shifted

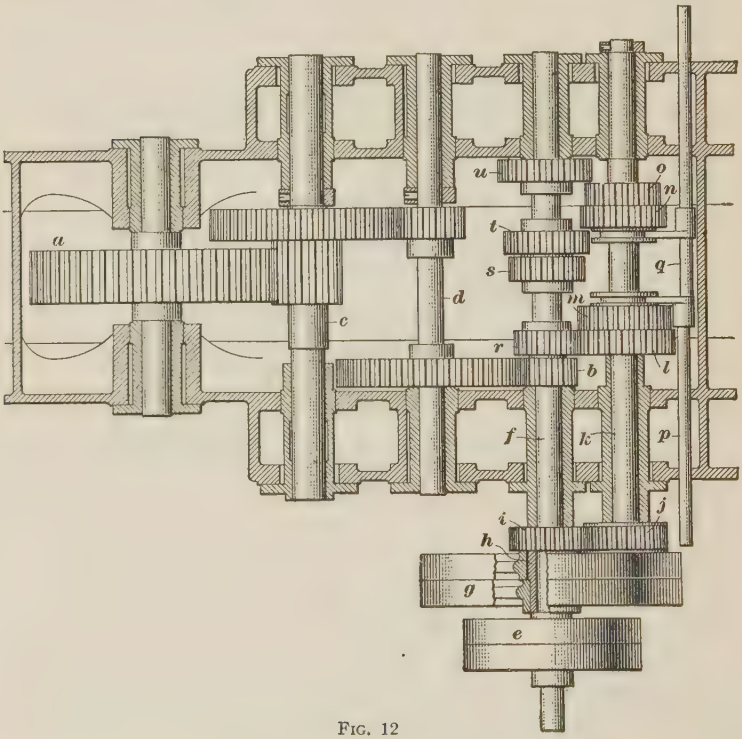

FIG. 12

by the rod *p* so that the gear *l* meshes with the gear *r* and the shaft *f* is then driven from the pulley *g* through the hub *h*, gears *i* and *j*, shaft *k* and gears *l* and *r*, thus turning the gear *b* and giving a slow motion to the table. By shifting the gear *m* into mesh with the gear *s*, a slower speed is obtained, and a still slower speed when the gears *n* and *t* are in mesh. The least cutting speed is obtained when the gear *o* is shifted to mesh with the gear *u*.

HOLDING WORK ON PLANER TABLE

VISES AND CHUCKS

30. Planer Vise.—The operation of fastening a piece of work to the planer table or in the vise is known as *setting the work.* It is very important that the work is set correctly and that it is held so that it is not sprung out of true. The size and shape of the piece have a great deal to do with the way it is to be fastened. A vise for holding work on a planer table is shown in Fig. 13. Its base is a circular plate *a* having a tongue on the bottom to locate the base in a T slot, so the fixed jaw will be parallel with the motion of the table. At each end above the tongue is a pocket and slot down through the base in which the holding-down bolts are placed, as shown at *b*. The base has graduations on its top edge so that the top *c* and face of the fixed jaw may be set to any angle with the motion of the table and clamped by the set-screw *d*. Sometimes the vise has a T slot in the bottom of the top and binder bolts passing into pockets in the base, for holding the top and base together.

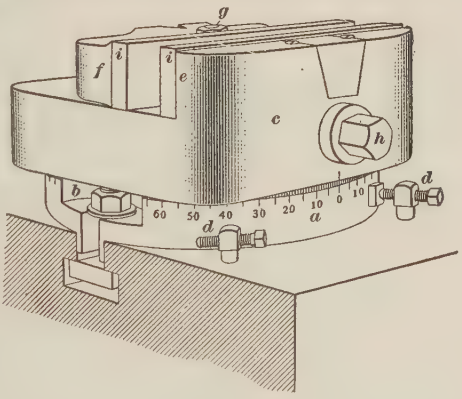

FIG. 13

31. The movable top of the vise in Fig. 13 has a fixed jaw *e* and a movable jaw *f* between which the work is clamped. The movable jaw is held in sliding contact with the vise body by the bolt *g* having a nut at its lower end through which passes the vise screw *h* used to tighten the movable jaw against the work. The back of the movable jaw has a V cut vertically in it which

may be swung around to face the fixed jaw for holding round work in a vertical position for planing. The soft cast-iron faces of the fixed and movable jaws are protected from wearing and injury by securing parallel steel false jaws *i* to their faces by filister-head screws. The steel jaws may be soft or they may be hardened and ground.

32. Magnetic Chuck.—The magnetic chuck, one form of which is shown in Fig. 14, holds the work by the action of electromagnets, without the aid of jaws or clamps. It consists of a plate *a* that is held firmly to the planer table *b* by clamps

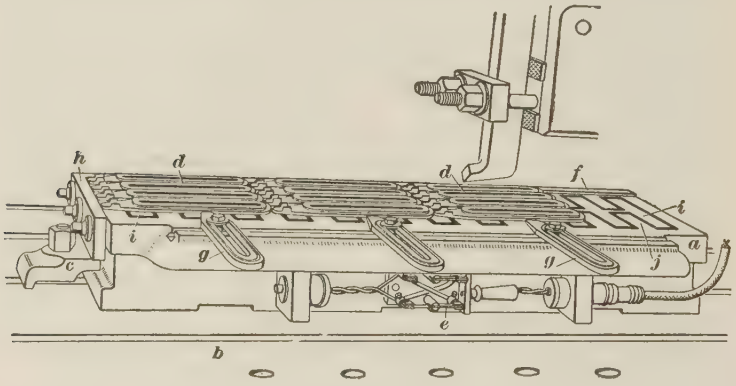

FIG. 14

and bolts, as at *c*. On the flat top the pieces of work *d* are laid, and when the switch *e* is closed the electromagnets inside the chuck hold the work down securely. The raised strip *f* and the stops *g* prevent sidewise motion and the stop-plate *h* prevents endwise motion. When the switch *e* is opened, the magnetic force ceases and the work may be lifted from the chuck. The face of the chuck consists of a number of positive pieces, or poles, *i* and negative pieces *j* arranged alternately. To be held firmly, the work should be placed on the chuck so that it will extend over at least one positive and one negative piece. The use of the magnetic chuck enables frail pieces of work to be secured quickly and easily, without springing.

PARALLELS, BLOCKS, PLUGS, AND STRIPS

33. Parallels and Parallel Blocks.—Parallels, which are pieces of cast iron or wrought iron, are usually made in pairs and are planed accurately to the same dimensions. They vary from 4 to 16 inches in length and are of any convenient width and thickness, being often made square. If parallels are made in sets, the width and thickness increase by quarters, eighths, or sixteenths of an inch, as may be most convenient. Parallel blocks are short parallels and are from $\frac{3}{4}$ to 2 inches square. They may be made by cutting a long parallel into short pieces; or, flat rolled steel ground to within 1 or 2 thousandths of an inch of standard size may be cut into parallel blocks.

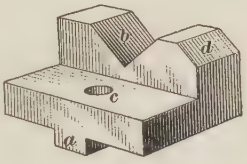

FIG. 15

34. V Blocks.—A form of V block used in planer work is shown in Fig. 15. It is an L-shaped casting having a tongue *a* on the under side of the base, parallel to the groove *b* in the upper edge. The tongue *a* fits into the T slot in the table and the planer bolt passes through the hole *c*. These blocks are generally used in pairs and it is a good plan to bevel one top

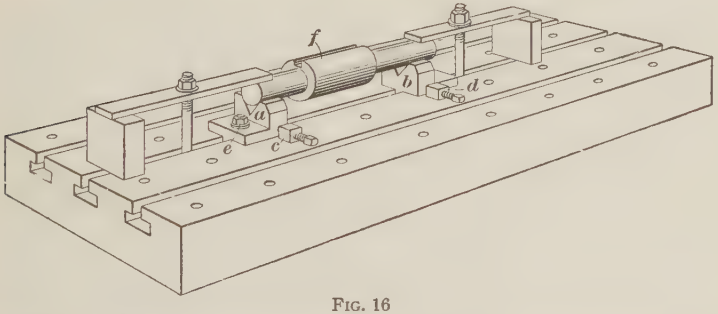

FIG. 16

corner of each pair, as shown at *d*, so that the workman will know at a glance whether they are properly located with respect to each other. They are used for holding round work exactly level and parallel with the T slots in the planer table, as shown in Fig. 16. The tongues of the V blocks *a* and *b* are forced

against the trued side of the T slot by the screw plugs *c* and *d* and are held firmly by the planer bolts *e*. A light truing cut is taken down the face of each V, and then the work *f* is placed so that parts of the same diameter rest in the grooves. The clamps should be put over the work at the V blocks. If a clamp is located at any point not directly over a V block, the

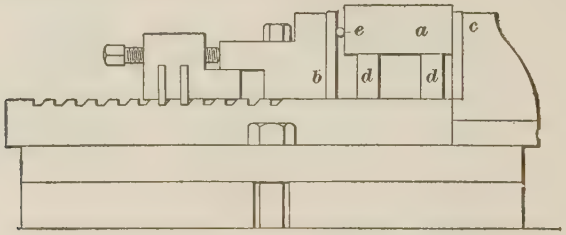

FIG. 17

work must be supported from beneath or it will be sprung out of shape. The angle of the groove in the V block is 90° for small work and 120° for large work.

35. Chucking Thin or Narrow Work.—If the piece of work to be planed is thinner than the depth of the chuck jaws, it must be blocked up by having parallels placed under it. A case of this kind is shown in Fig. 17, in which the piece of work *a* is held above the upper edges of the jaws *b* and *c* by the pair of parallels *d*. A strip of paper should be placed at each end of each parallel, under the piece of work. When all the strips are held tightly it is known that the work is resting solidly on the parallels. A piece of round stock *e* is placed between the jaw *b* and the work *a*. This transmits the pressure of the jaw *b* in such a way that the work is forced squarely against the fixed jaw *c*, while it rests on the parallels.

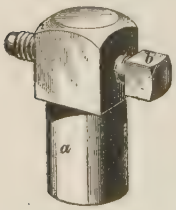

FIG. 18

36. Screw Plugs.—One form of screw plug for holding a piece of work to the planer table is shown in Fig. 18. It is made from a piece of square steel on which a round shank *a* is turned to fit the holes in the table. A hole is drilled through the square head, sloping downwards at an angle of about 5° with

the horizontal, and this hole is tapped to receive the setscrew *b*. The use of screw plugs is confined mainly to work of medium or light weight and is illustrated in Fig. 19, which shows the method of holding a casting *a* that is to be planed over the top. The casting is placed lengthwise on the table *b* and a screw plug *c* is inserted in a hole near each corner of the work, along the side. A piece of card *d* is placed under each corner of the work, and if the casting is not true, it will rock. To prevent this, more pieces should be put under the loose corners until the work rests firmly, without rocking. The setscrews in the plugs *c* are then tightened against the sides of the work. If the casting is now found to be raised, so that the card packing is loose at

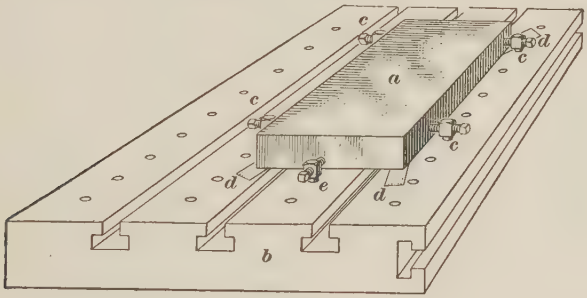

FIG. 19

the corners, the plugs *c* should be driven down until the card strips are held tightly all around. A plug *e* at the end prevents endwise motion of the work.

37. Lining Work by Screw Plugs.—Work held by screw plugs may easily be lined. A tool is clamped in the tool holder and is set so that its point is directly over one edge of the work, near the end. The planer table is then run back and forth under the tool, and if the work is not in line, the edge will not be beneath the tool point at the opposite end of the stroke. To bring it into line, the screw plug at one side is loosened and the opposite one is tightened, and this is repeated until the edge follows the point of the tool through the entire stroke. If the surface of the work has scribed on it a line that is to be set parallel to the direction of motion of the table, a sharp-pointed

tool is used, and the screw plugs are adjusted as already described, until the tool point follows the line exactly.

38. A piece of work held by screw plugs may have a finished side surface that must be set parallel to the line of motion of the table. The screw plugs are adjusted until a steel rule inserted between the tool point and the surface is held with the same pressure at each end of the piece of work. The tool point is then run very close to the surface and the screw plugs are further adjusted until the tool touches the work with a slight but uniform contact throughout the whole return stroke. This contact may be felt by holding the hand against the tool clamp. A still more accurate way is to make the test during the cutting stroke; but the tool must only scrape the work lightly and must not cut it.

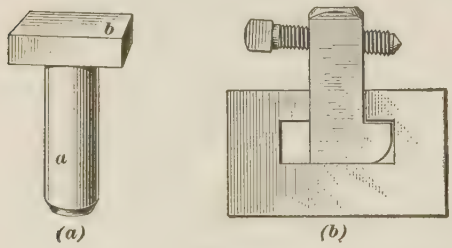

FIG. 20

39. Stop-Pins, Thrust Blocks, and Stakes.—The stop-pin is used to prevent work from slipping under the pressure of a cut. As shown in Fig. 20 (*a*), it consists of a pin having a round shank *a* that will fit the hole in the planer table, and a square head *b* from $\frac{1}{4}$ to $\frac{1}{2}$ inch thick. The thrust block, shown in (*b*), is a rectangular piece made to be slid into a **T** slot and having a shoulder at its lower end to prevent it from being pulled out of the slot. A setscrew is screwed through the top, and is slanted at a slight angle. Thrust blocks are used mainly on tables that have only **T** slots and no holes for plugs. Stakes are used instead of stop-pins for holding large work. They are made either round or rectangular to fit the holes in the planer table and at the upper end are slightly larger than the hole, a shoulder being formed so that they cannot slip through.

40. Parallel Strips.—A parallel strip is a piece of cast iron of convenient length having a rectangular or an **L** section and is used to prevent sidewise movement of a piece of work on the planer table and also to line the work parallel with the table.

The rectangular form is shown at *a*, Fig. 21 (*a*), and the piece of work *b* is held against it by the screw plugs *c*. The bottom of the strip is planed true and is formed with a tongue *d* about $\frac{1}{4}$ inch high and from $\frac{1}{8}$ to $\frac{3}{16}$ inch narrower than the width of the T slot. A wedge, such as a cut nail, is driven at each end

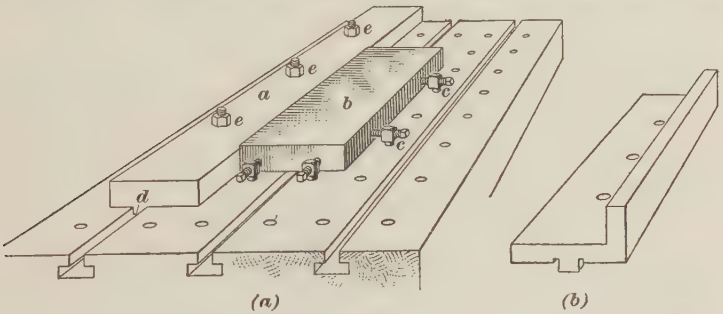

FIG. 21

between the side of the tongue and the side of the T slot to force the strip against the opposite side of the slot, where it is held by tightening the nuts *e*. The L form of parallel strip is shown in (*b*). Instead of one long strip, two short strips may be used, one being placed near each end of the work. The piece to be planed is thus held parallel to the line of motion of the table.

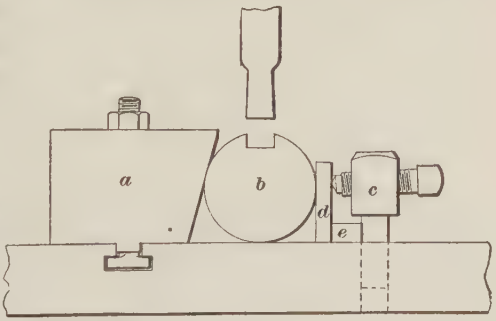

FIG. 22

41. A special parallel strip for holding round work in which a slot is to be planed is shown at *a*, Fig. 22. One side of the strip is planed so that it makes an angle of 15° or 20° with the vertical. The work *b* is placed against this slanting face and is held there by screw plugs *c* that are set just above the center. The set-screw presses against a packing piece *d*, so as not to dent the work, and a block *e* prevents the packing piece from tipping.

Before a parallel strip is used for accurate work it should be trued. A cut is taken down its face with a side tool and this face is then tested with a try square. If the face is not square with the table, the head should be readjusted and truing cuts should be taken until the face is square with the surface of the table. When this has been done, work held against the strip will be planed square.

42. Cross-Parallel.—If a cut is to be taken crosswise of the work or at an angle to it, the work should be clamped against a cross-parallel, as shown in Fig. 23. The cross-parallel *a* is a strip of cast iron about as long as the table is wide, from 1 to 2 inches thick, and from 3 to 4 inches wide. It is made larger than this for use on large planers. It should be planed true all over, and a hole should be drilled at the center for the clamp bolt *b*. The top surface and the face against which the screw plugs *c* bear may become dented, but the bottom and the face against which the work is held must always be kept true and free from dents.

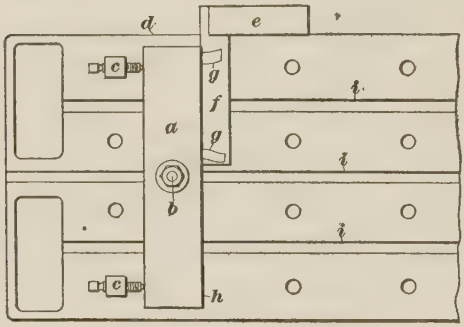

FIG. 23

43. Setting of Cross-Parallel.—The cross-parallel is first placed on the planer table with its working face toward the cross-rail, and the clamp bolt *b*, Fig. 23, is drawn up loosely. The screw plugs *c* are placed in two outer holes behind the cross-parallel, and the latter is then set square with the back edge *d* of the table by the use of a try square, as shown. The beam *e* of the try square is held flat against the edge *d* and the blade *f* is brought up against the cross-parallel. Strips *g* of tissue paper are placed between the blade and the parallel, and the tightness with which these are held is tested by pulling them gently with the free hand. If one strip is tight and the other is loose, the

setscrew in the proper plug should be tightened, and this should be repeated until both strips are held with the same pressure. The clamp bolt *b* is then tightened, and if the paper strips are still held evenly the cross-parallel is squarely set. A true side of the piece to be planed is then set against the working face *h* and the work is fastened by screw plugs and clamps. The back edge *d* and the back edges *i* of the slots are always trued when a planer is erected, and a piece of work may be lined or

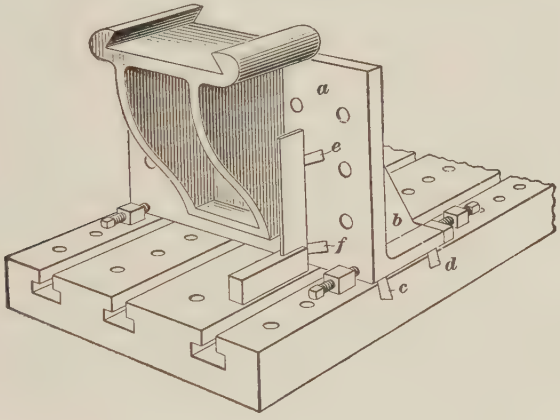

FIG. 24

squared from them. A bevel protractor is used to set the cross-parallel when a cut is to be taken at an angle to the edge of the work.

44. Angle Plate.—An angle plate, shown at *a*, Fig. 24, is an L-shaped casting whose outer faces are planed true and at right angles to each other. Ribs or webs *b* at the back brace the two sides, which are drilled with holes or slotted to receive bolts by which the angle plate may be held to the table and work may be held to the angle plate. A drilled plate is stronger than a slotted one. The angle plate is used to hold work that has two surfaces that are to be planed square with each other, or that has one side that is of such shape as to prevent it from being clamped directly to the table. It is usually set either parallel to the line of motion of the table or square with it.

45. Setting of Angle Plate.—Because of the severe treatment it receives, the angle plate does not remain true very long, and therefore it must always be set carefully. It is first set square with the table vertically, as shown in Fig. 24, the stock of the try square being placed on the table and the blade against the angle plate. Strips of paper are inserted under the base of the angle plate at *c* or at *d*, as required, to bring the upright part true against the try square, so that the paper strips at *e* and *f* will be held with the same pressure. These operations must also be carried out at the other side of the angle plate. The angle plate is then set square with the back edge of the table, by the use of a try square in the same way as for setting the cross-parallel, and is clamped down, after which it is tested again, to make sure that it has not been moved by the clamping. The table must not project over the end of the bed while the angle plate is being set, as the spring or sag will result in a faulty setting. The working side of the angle plate should face away from the cross-rail, as shown, so that all springing will be away from the cutting tool and chattering will be prevented. If the work is large, the overhanging part should be supported by a bracket or jack so as to prevent its springing down from the pressure of the tool.

BOLTS, CLAMPS, AND DOGS

46. Planer Bolts.—When the work is too large to be held by screw plugs or by chucks, it is fastened by bolts and clamps. The square-headed bolt shown in Fig. 25 (*a*) is the strongest form. The head is inserted into a T slot at the end of the table and the bolt is moved along the slot to the desired position. The quarter-turn bolt shown in (*b*) has a narrow head that may be slipped into a T slot at any point, after which a quarter turn brings the ends of the head under the lips of the slot. The form shown in (*c*) consists of a nut that is slipped into the end of the T slot and is moved along to the required position, after which the bolt is put through the clamp and is screwed into the nut. If desired, a stud threaded at both ends may be screwed into the nut in the slot and a nut may be screwed on the upper end.

47. Flat Clamps.—The flat clamp consists of a piece of flat iron or steel stock of convenient length and 2 inches by $\frac{5}{8}$ inch in section, with a hole drilled through it near one end. The use of flat clamps is shown in Fig. 26, in which a piece of work *a* is held by clamps *b* and bolts *c*, the parallel blocks *d* being

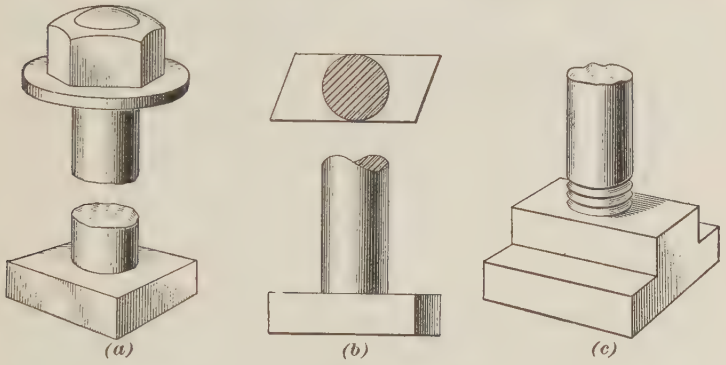

FIG. 25

used to bring the clamps fairly level. Stop-pins *e* prevent slipping. The bolts should be as close as possible to the work, so that the greatest pressure is put on the work and not on the blocks; also, the blocks should be a little higher than the point where the clamp rests on the work. A piece of card under the

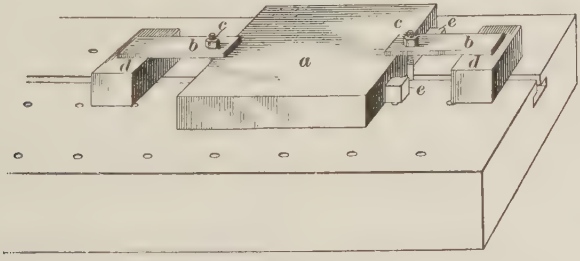

FIG. 26

end of the clamp will prevent it from injuring finished surfaces; also, a piece of smooth iron stock between the clamp and the work will give a better bearing.

48. Gooseneck and U Clamps.—The application of the gooseneck clamp is shown at *a*, Fig. 27. Because of its shape

a shorter bolt may be used than with a flat clamp, and it is also less in the way. The **U** clamp is a piece of square iron

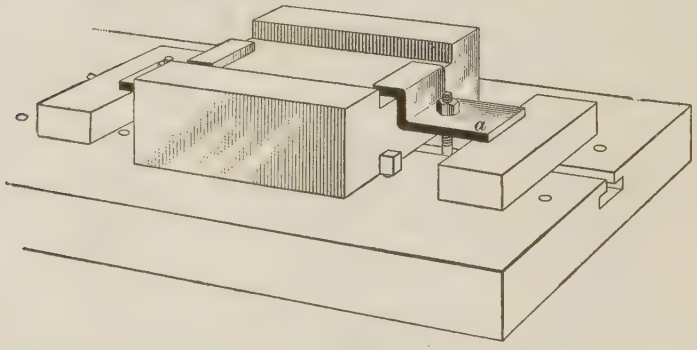

FIG. 27

or steel bent to the shape shown in Fig. 28. The shank of the bolt passes through the slot between the arms and a washer under the nut forms a good bearing on the clamp. The bolt may be placed in any position in the slot.

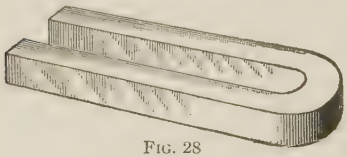

FIG. 28

49. Right-Angle and Finger Clamps.—The bent clamp shown in Fig. 29 does away with the use of a packing block, as the short end of the clamp is as long as the work is high. This end should be machined so that it will rest squarely on the table. The finger clamp is shown in Fig. 30. The end that holds the work is drawn or turned to a cylindrical shape, and fits into a hole that is chipped or drilled in the work *a*. The other end *b* is like a flat clamp. Finger clamps are used to hold work that must be planed over its entire top surface.

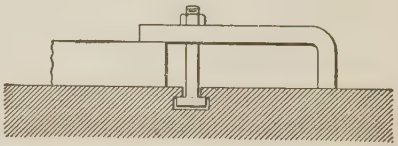

FIG. 29

50. Wedge Clamps.—If the work cannot be held by finger clamps and yet the holding devices must be kept below

the surface of the work, wedge clamps may be used, as illustrated in Fig. 31. A flat clamp *a* is set so that one end rests against the work *b* at a point just below the upper edge and the other end butts against a cross-piece *c* that is held from slipping by screw plugs *d*. A washer *e* that is thicker at one side than at the other is placed under the nut of the planer bolt *f*, so that the nut is level, and the nut is tightened. The clamp is thus wedged in firmly and the piece *b* is held securelv.

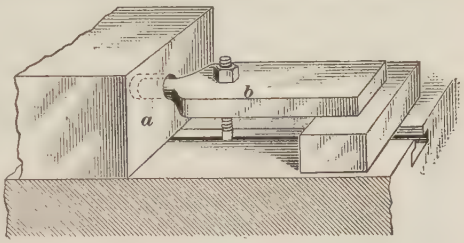

FIG. 30

51. Toe Dogs.—Thin work may be fastened to the table by the use of toe dogs in connection with screw plugs. The

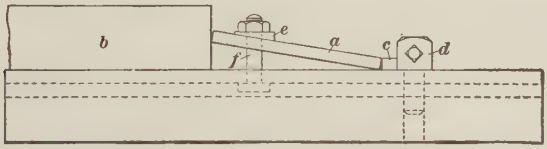

FIG. 31

toe dog, as may be seen in Fig. 32, is a piece of steel from 2 to 4 inches long, with one end flattened to a chisel shape and the other end cupped to receive the setscrew of the screw plug. In Fig. 33 a piece of thin work *a* is held by the use of a straightedge *b* and the toe dog *c*. The parallel *d* is grooved along one face to receive the back of the straightedge, and the work is gripped by screwing up the setscrew against the end of the toe dog. If the work is long, two or more toe dogs should be used. The toe dog should slant downwards, but not at too great an angle, or it

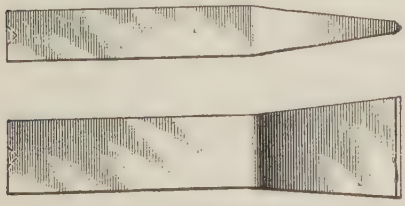

FIG. 32

will slip off the edge of the work. The thin end of the toe dog may be hardened, so that it will cut into the work to be held and thus be kept from slipping, but in many cases the end is rounded. If the face of the work is finished and it is not to be marred, a piece of sheet copper should be placed between it and the toe dog.

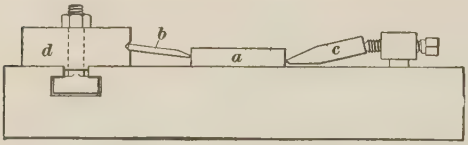

FIG. 33

PLANER JACKS AND CENTERS

52. Planer Jacks.—The planer jack, illustrated in Fig. 34, is made in different sizes and is used to support work. It consists of a body *a* in which is a screw *b* with a square head. Holes drilled through the head allow a bar *c* to be inserted so as to turn the head up or down. A cap *d* is fixed to the head *c* by a ball-and-socket joint, so that it can adjust itself to the surface of the work. The face of the cap is checkered so that it will not be so apt to slip. The special jack, or brace, shown in Fig. 35 is useful where screw plugs and stakes are insufficient and ordinary jacks cannot be used. It is a box-shaped casting of a size to suit the work, planed smooth on the bottom and on the front, so that either face may be laid against the table. No tongues are provided, and the jack is held to the table by bolts and screw plugs. Holes may be drilled and tapped in any part of the jack to suit the work to be held. The horizontal screw *a* is used as a side support and the vertical screw *b* acts as a jack under an overhanging part. These screws may be used in any of the holes, as needed.

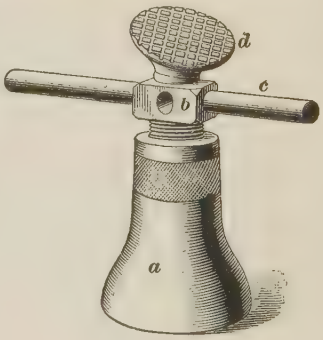

FIG. 34

53. Planer Centers.—Planer centers are used for holding work that must be rotated so that it may be planed on several

surfaces, or so that slots may be spaced and cut on the face of the work. The set of planer centers shown in Fig. 36 (*a*) and (*b*) consists of a headstock and a tailstock, both of which have tongues on the bottom to fit the T slots of the planer table, to insure that they will be in line with each other and with the line of motion of the table. The work is held in the same way as in lathe centers. The tail of the dog fastened to the work fits in the slot in the arm *a* on the headstock spindle. On the other end of the spindle is a worm-wheel *b* that may be turned by turning the handle *c*, which drives the worm *d* meshing with the worm-wheel. The face of the worm-wheel has several rows of holes, equally spaced, arranged in circles, forming what is called an *index plate*. An arm *e* pivoted to the headstock carries a latch pin *f* that fits the holes, and by the use of the latch pin in connection with the handle *c* for turning the worm-wheel, or index plate, a number of equal divisions on a piece of circular work may be obtained.

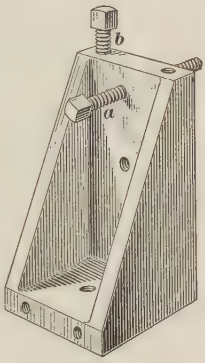

FIG. 35

54. Division by Index Plate.—In order to find out whether a desired number of equal divisions of a circle can be

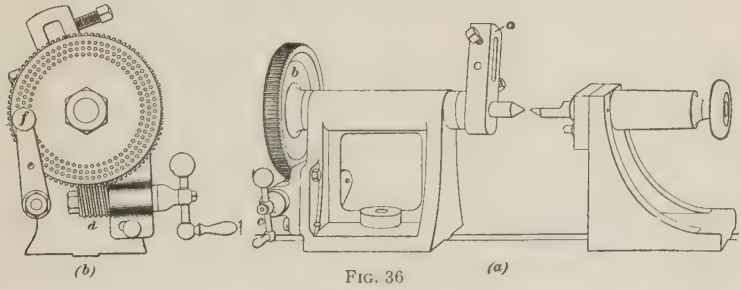

FIG. 36

obtained with a given index plate, the following rule may be used:

Rule.—*Divide the number of holes in the row by the number of equal parts into which the circle is to be divided, and if the*

quotient is a whole number, without any remainder, the number of divisions can be obtained. This whole number then represents the number of holes the latch pin must be advanced, not counting the hole in which it rests at the start.

As there are several rows of holes in the index plate, the rule must be applied to the several rows in succession, until one is found that can be divided without a remainder. If no such row can be found, some other method must be adopted.

EXAMPLE.—An index plate on a planer center has three rows of holes containing 72, 60, and 56 holes, respectively. Can a circle be divided into 14 equal parts with this index plate?

SOLUTION.—Applying the rule to the outer row, $72 \div 14 = 5\frac{1}{7}$, which shows a whole number with a remainder; hence, the outer row cannot be used. Trying the next row, $60 \div 14 = 4\frac{2}{7}$, which also shows a remainder, so that the middle row cannot be used. Trying the inner row, $56 \div 14 = 4$, which is a whole number without a remainder; therefore, by using the row containing 56 holes, and moving the latch pin 4 holes at a time, 14 equal divisions can be obtained. Ans.

SPECIAL HOLDING DEVICES

55. Special Braces or Jacks.—If the piece of work is high and has a small supporting base, it is liable to tip under the pressure of the cut. This tipping may be prevented by the use of braces or jacks, as shown in Fig. 37, in which two large pillow-blocks for a steam engine are braced and supported by the jacks *a*. The body of each brace is simply a piece of pipe of suitable size. At the lower end is a swivel *b* that fits in one of the holes in the table and at the upper end is a block *c* with a screw cut on its shank. The shank is fitted with a nut *d* and extends into the pipe. By turning the nut *d*, therefore, the block is forced against the work, acting as a jack.

56. Jigs and Gang Fixtures.—If a number of similar pieces are to be planed one after another, it is a good plan to make a special jig to hold them. The jig should be designed to hold the work securely, but at the same time to allow it to be removed quickly and replaced by another piece. In this way

much time may be saved. In case it is not possible to clamp a string of pieces directly to the table, a number of jigs are made exactly alike and are clamped on the table, and the pieces of work are held in these. The cuts are then taken over all the pieces as if they were one piece of work.

57. Holding Heavy Work.—Some pieces of work, because of their peculiar shape and great weight, require special holding

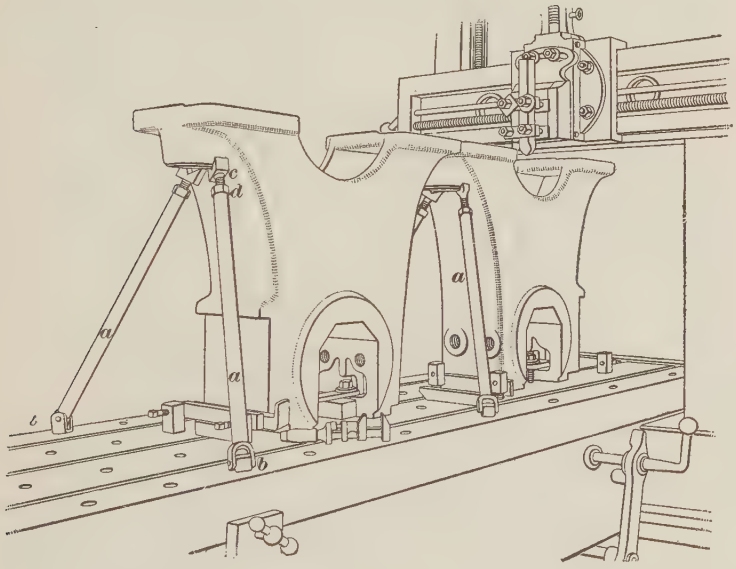

FIG. 37

devices; for example, the two pieces shown in Fig. 38, which are parts of the frame that supports the cylinder of a vertical engine, are carried on a yoke *a* that is formed to fit the curved castings and is bolted to the table. The flange on the casting keeps it from slipping down and setscrews *b* at the side of the yoke are used for adjusting the work. The lower end of the casting overhangs the table and is kept from slipping lengthwise, when a cut is being taken, by the use of a heavy bar *c*, which is bolted to the table. A setscrew *d* in the end of the bar is used to make slight adjustments when setting the work true. Planer jacks *e* are also used to keep the work from slipping and tipping.

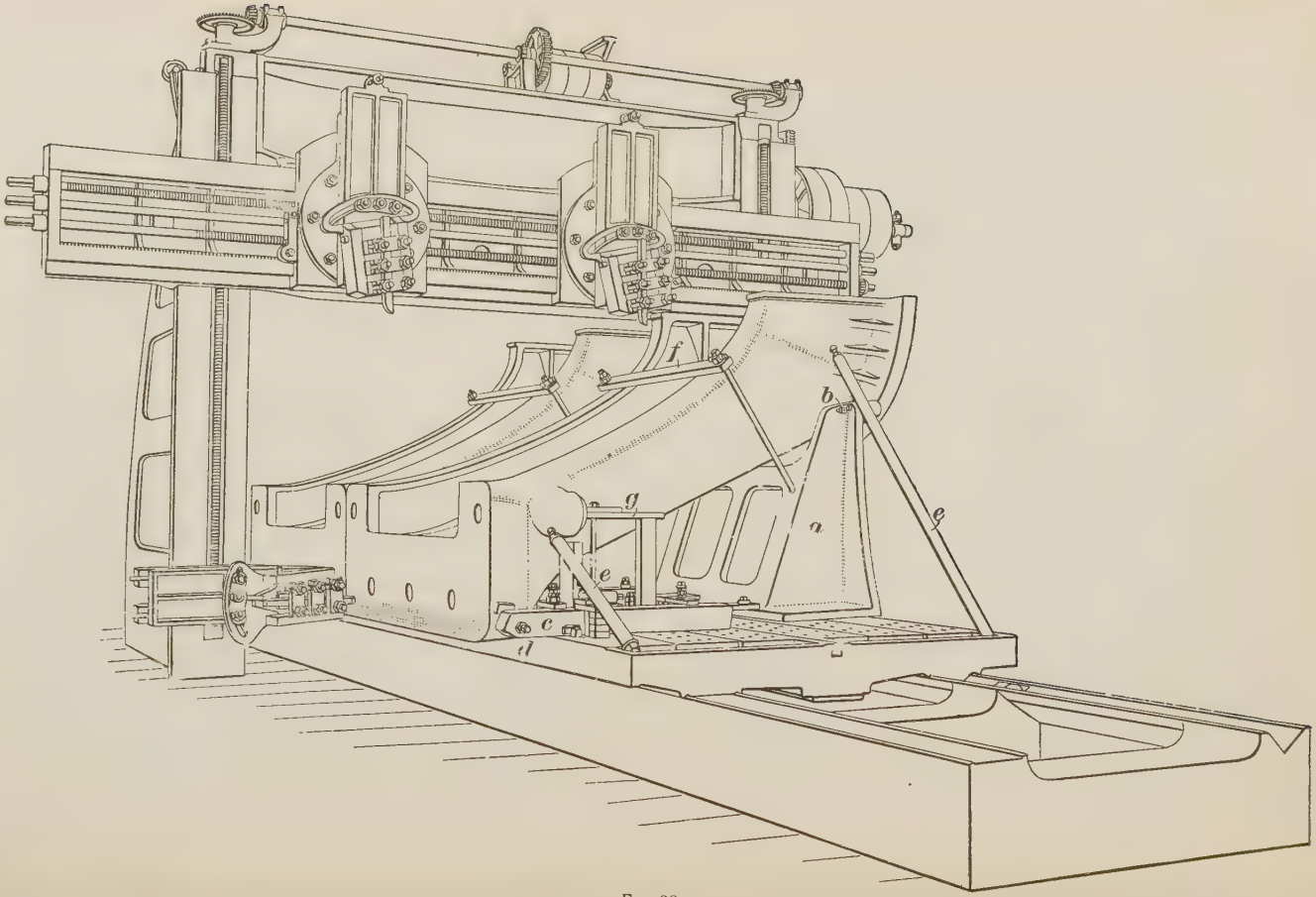

Fig. 38

The clamps for holding down the work are shown at *f* and *g*. When such heavy work as this is securely braced and rests fairly on a special fixture or special holding device, its weight helps to hold it down, so that very heavy clamps are not necessary.

OPEN-SIDE PLANER

58. The open-side planer, shown in Fig. 39, is intended to be used for work that is too wide or too irregular for the ordi-

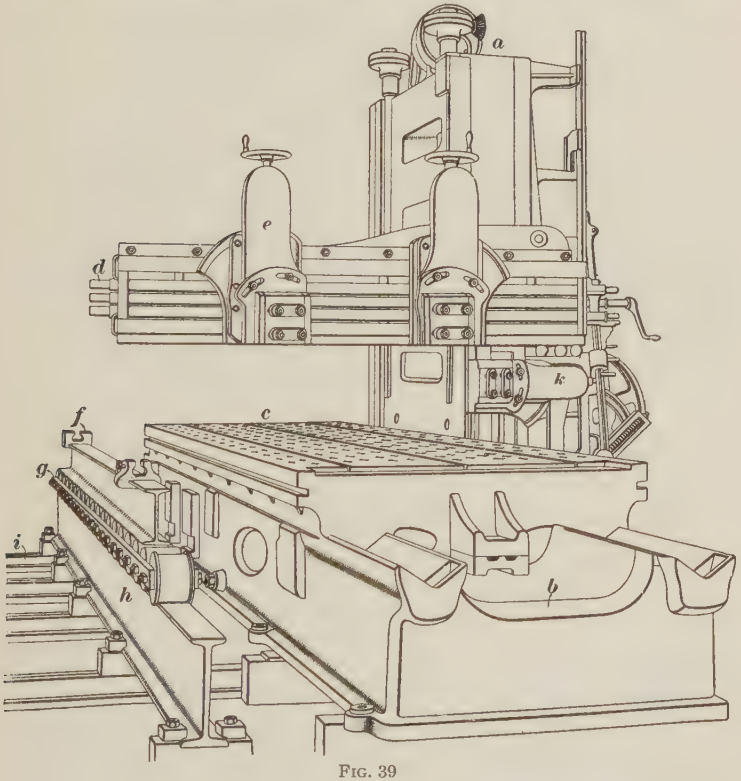

FIG. 39

nary planer. It consists of one heavy upright *a* attached to a bed *b* that carries the table *c*. This table is usually made somewhat heavier than would be the case with an ordinary planer

having the same width. The cross-rail *d* is supported from one end only by the housing, or post, *a*. A heavy brace is fitted between the back end of the upright and the outer end of the cross-rail *d* to make the cross-rail as stiff as that ordinarily supported by two housings.

One or more planer heads *e* are carried on the cross-rail and a side head *k* on the upright. An auxiliary rest *f* is provided, which runs on a series of rollers *g* on the top of the **I** beam *h* to support the end of work that overhangs the planer table. The **I** beam supporting the rest can be moved toward or away from the planer bed by adjusting it along the supports *i*. Both the bed and the supports for the rest should be placed on the same rigid foundation. The table is usually driven by a spiral gear. The cross-rail of the open-side planer is raised and lowered by two elevating screws, as in the ordinary planer, one screw lifting the cross-rail proper and the other the rear end of the brace. Some open-side planers are provided with a detachable housing that is used when the planer is working on ordinary work and that is removed when the work is too wide to pass between the housings. This gives additional stiffness to the cross-rail.

PLANER WORK

(PART 2)

CUTTING WITH PLANER

PLANER TOOLS

ROUGHING TOOLS

1. Comparison of Planer Tools and Lathe Tools. Planer tools differ a little in shape from lathe tools, depending on the properties of the metal to be cut and whether the cut is a roughing or a finishing cut. They are made for use on flat surfaces, mainly, and the angles of rake and clearance cannot be altered by changing the position of the tool with respect to the work, although they may be changed by grinding. The position of a planer tool with respect to the work is the same as that of a lathe tool that has its point set level with the center of the work. Planer tools are given an angle of clearance of from 3° to 5°.

FIG. 1

2. Ordinary Roughing Tools.—The shape of the ordinary roughing tool for planer work is shown in Fig. 1. The point of the tool extends above the face of the shank, or body, and the face of the cutting part is inclined. The tool shown in Fig. 2 is upset at the end so as to bring the cutting edge *A B* above the surface of

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the shank, and the face is made slanting, so that the lower edge *C D* is almost even with the surface of the shank. The tool in Fig. 1 has a curved cutting edge and will therefore produce a curved chip. The tool in Fig. 2 produces a nearly flat chip, which is easier to bend than is a curved chip.

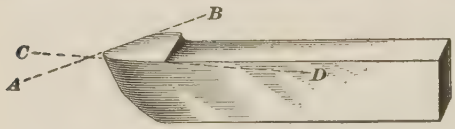

FIG. 2

3. The **clam-shell tool,** shown in Fig. 3, is first forged straight, like an ordinary side tool, and is then bent. This tool is used for heavy roughing cuts, the cutting being done by the outer curved edge. Its principal advantage is that it may be sharpened easily, as only a little metal need be ground off the beveled edge; also, in making this tool, it is easier to draw the cutting edge above the face of the shank than it is to upset the whole end, as in Fig. 2.

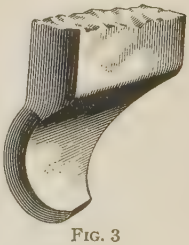
FIG. 3

4. The **round-nosed tool,** shown in Fig. 4, is made by drawing down the stock, from the back and both sides, nearly to a point. The tool is then ground flat on the front face and on both sides as far as the cutting edges are to extend, and the point is rounded. The advantage of this tool is that it may be started in from either side of the work, or it may be started in anywhere between two raised parts of the work and fed horizontally in either direction. It is used mainly for planing cast iron, wrought iron, and steel, but it may also be used for planing brass, bronze, Babbitt, and similar metals.

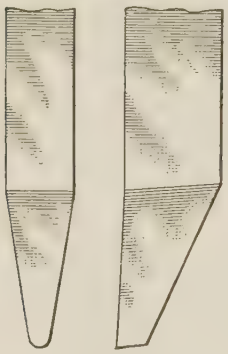
FIG. 4

5. Tools for Side or Down Cuts.—Two forms of broad-nosed tools for side or down cuts are shown in Fig. 5 (*a*) and (*b*). The squaring-down tool with rounded corners, shown in (*a*),

will take the heavier cut and will not break out the metal *a* at the bottom of the cut. The similar tool shown in (*b*) has sharp

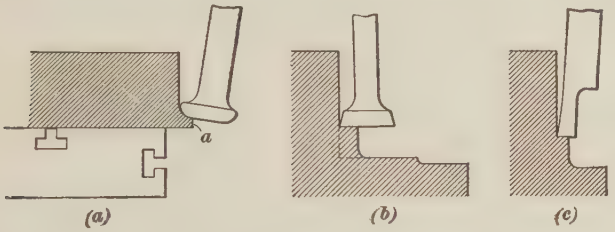

FIG. 5

corners and is used for squaring down where a square corner must be left. The form shown in (*c*) is used in narrow spaces and is made either right hand or left hand. All three tools are shown properly set for side cuts. When properly sharpened, the tool shown in (*a*) is sometimes used as a finishing tool, the depth of the cut being from $\frac{1}{32}$ to $\frac{1}{16}$ inch, and the feed about the same as for a roughing cut. The rounded corner leaves a smooth surface.

6. Diamond-Pointed Tool. — The diamond-pointed tool for the planer, shown in Fig. 6, is stronger than that used in the lathe, as it has no notch where the point joins the shank. It is largely used for roughing cuts on steel and wrought iron, as any desired angle of keenness may be obtained by grinding off the front, or cutting, face. It cuts a flat chip, which is easily bent. When well sharpened it makes a very good finishing tool, especially on light work, where a narrow-pointed tool and light feed must be used. The diamond-pointed tool may be used for planing Babbitt metal, also.

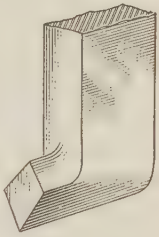

FIG. 6

FINISHING TOOLS

7. Broad-Nosed Finishing Tools.—The finishing tool for cast iron is of the square-nosed form shown in Fig. 7, and that for wrought iron or steel is of similar form but has a shorter cutting edge. The broad-nosed finishing tool is ground flat

on the face *a* that turns the chip, has enough front rake to give a keen cutting edge, and has as little clearance as it can have and yet cut freely. The cutting edge *b* is ground nearly straight

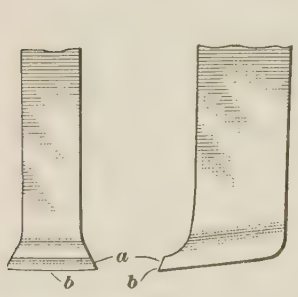

FIG. 7

FIG. 8

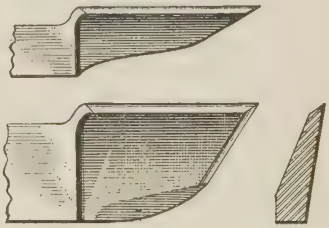
FIG. 9

for about three-fourths of its length, the portion on each side being curved slightly so that lines will not be cut on the finished surface. The round-nosed tool shown in Fig. 1 is often used for finishing wrought iron and steel, in which case the curve at the point is made much flatter, or even straight for $\frac{1}{8}$ inch or so.

8. Narrow Finishing Tool.—A finishing tool like that shown in Fig. 8 is to be used at the bottom of a groove, or between two raised parts, where it must be fed in each direction. It is similar to a wide parting tool, is ground straight on its cutting edge, and is rounded at the corners with an oilstone. It is set so that it cuts equally along the whole edge.

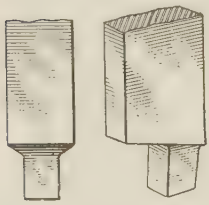
FIG. 10

9. Side Tools for Finishing.—In the finishing tool for side cuts, shown in Fig. 9, the cutting edge is parallel with the shank and somewhat higher than the shank when the tool is new. The cutting edge is straight and should always be kept in line with the shank; also, it should be higher at the point than at the shank end. The side face is ground with good clearance and the top face with enough rake to give a keen cutting edge. The side face below the cutting edge must be nearly flat, except for a

FIG. 11

slight curving for a short distance back from the point. The curve and the side face should be ground and tried repeatedly until the tool, after being oilstoned, cuts a smooth surface. It is resharpened by grinding the top face only, and then oilstoning it, thus saving the time and expense of grinding the working face. All finishing tools should be oilstoned before being used.

10. Underhung Finishing Tool.—On some classes of thin work an ordinary finishing tool will cause chattering; to prevent this, the underhung tool shown in Fig. 10 may be used. The cutting edge is nearly flat and from $\frac{5}{16}$ to $\frac{3}{8}$ inch wide, and is set back about two-thirds of the depth of the shank. This tool should be set so that the leading corner is somewhat lower than the other.

11. Finishing Tool for Steel.—The special finishing tool shown in Fig. 11, intended for use on wrought iron or steel, is made like an ordinary parting tool with an end about $\frac{3}{16}$ inch thick, and is then twisted until the cutting edge is diagonal. It is given about 3° of clearance and has a considerable curve from front to rear. The curve and the twist give a shearing cut that produces a very smooth surface.

12. Machine-Ground Tools.—A few typical planer tools ground on one of the standard tool grinders are shown in Fig. 12, and in Fig. 13 some special tools. Fig. 14 shows a chart that is sent out with Sellers' grinding machine, giving the clearance angles for grinding the different tools. The numbers placed opposite the tools in Fig. 12 correspond to similar numbers on the shanks of the tools in Fig. 14. In the case of the side-finishing planer tools illustrated in Fig. 14 it will be noticed that two angles are given for *d*. The upper angle is the top side rake, at right angles to the cutting face, and the lower angle is the top rake in the direction of the cutting face. These charts and figures are given simply to show what is considered good practice in regard to the shape of the tools.

13. Special Forms of Finishing Tools.—Broad-nosed finishing tools, if forged from solid stock, are expensive. For this reason various forms of special tools, in which the cutting

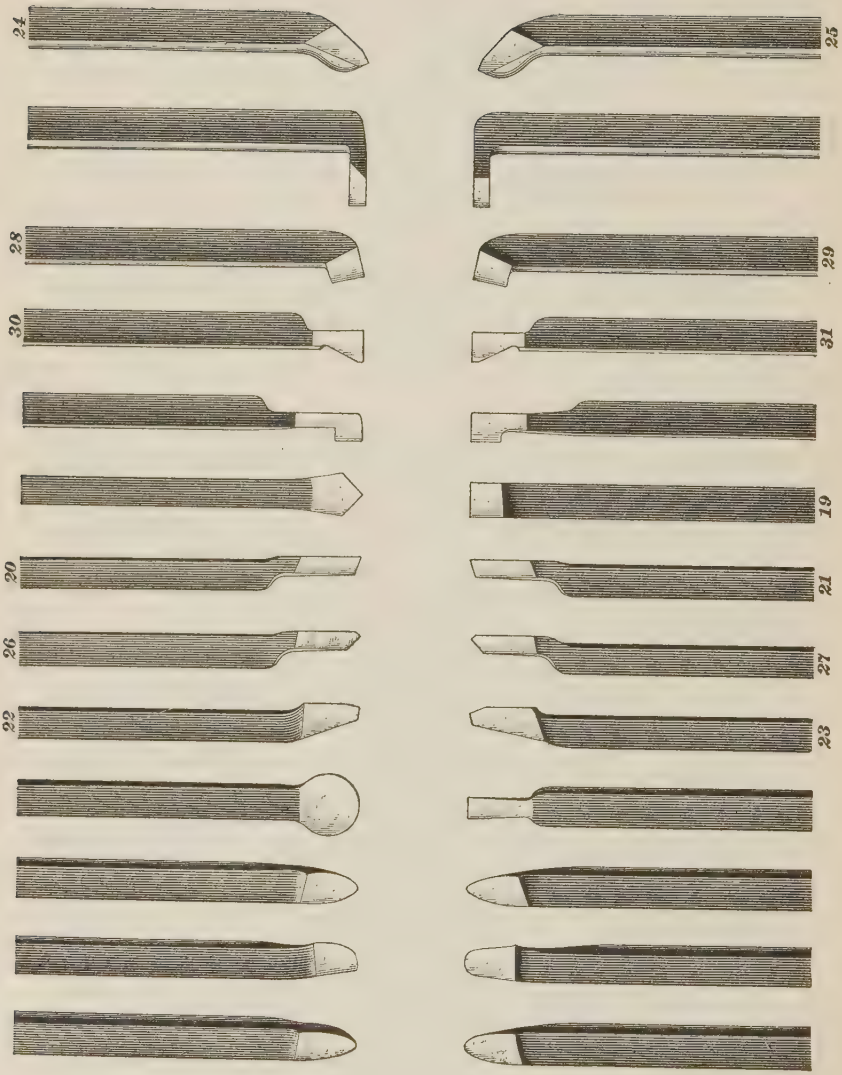

FIG. 12

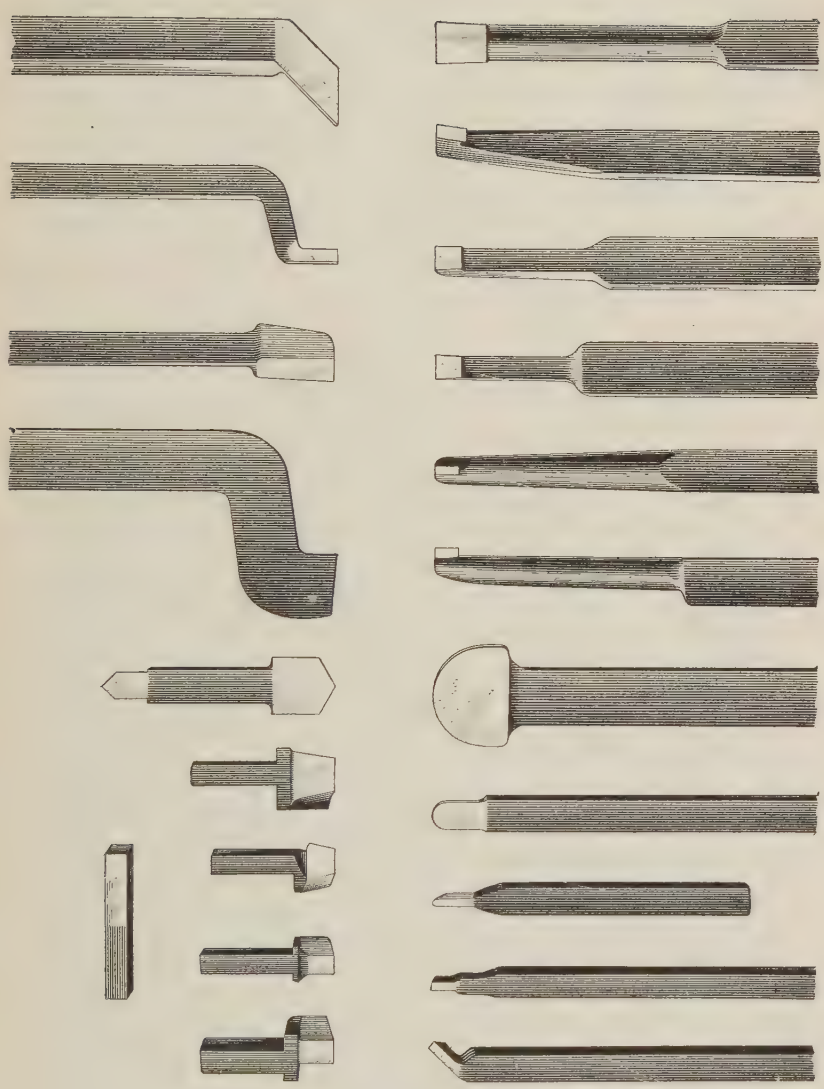

Fig. 13

edges are formed on small pieces of steel bolted or clamped to a holder, are often used. Fig. 15 shows three tools of this class. The one shown in (*a*) is intended for finishing very broad surfaces. The steel tool *a* has a cutting edge *b c* and is clamped to the shank *d* by two capscrews. The tool shown in (*b*) is intended for finishing a narrower flat surface, having a square corner.

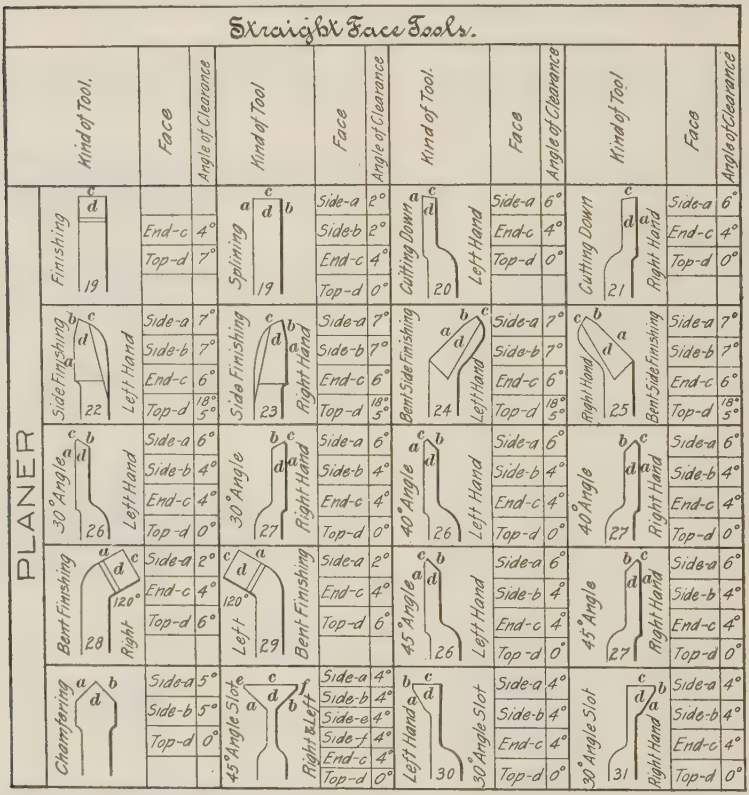

Fig. 14

The steel tool *a* is made square, with four cutting edges as *b c*, any one of which can be brought into the cutting position. The tool shown in (*c*) is intended for finishing a fillet of large radius. The cutter *a* is circular in form, the cutting being done along the edge *b c*. The cutter can be rotated on the clamping bolt and clamped in any desired position, so that all parts of the

edge can be used before resharpening. All these special tools are underhung; that is, the steel tool proper is clamped to the

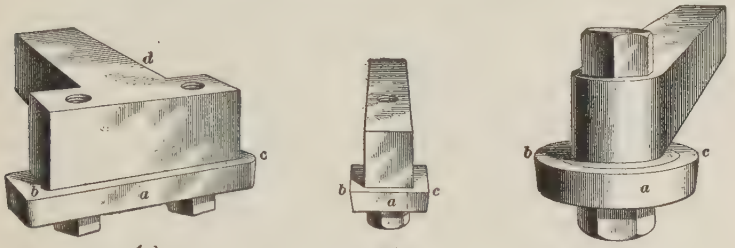

FIG. 15

back side of the shank. Cutters or blades having irregular outlines may also be used on shanks similar to those shown.

TOOL HOLDERS

14. Requirements of Good Tool Holder.—Tool holders of various forms are used to reduce the cost of steel for cutting tools. The tool holder consists of a shank of machinery steel having at the end a holding device in which is fixed a small cutting tool of carbon steel or of high-speed steel. This small tool requires much less steel and is cheaper than a tool in which both the shank and the cutting end are of tool steel. A tool holder intended to be used on a planer should have a very stiff shank and should not only hold the tool firmly, but should support it close to the cutting edge. A good form is shown in Fig. 16, as the tool may be set in line with the shank for planing horizontal surfaces, or may be turned to the right or to the left for side cuts. In some cases, the tool should be reversed, so that the holder travels ahead of the tool, as this will prevent chattering.

FIG. 16

15. Plain Tool Holders.—A plain tool holder of large size is often made by cutting a slot, slightly larger than the stock of which the tools are made, in one side of a bar of square

steel. The front side is then drilled and tapped for two setscrews to hold the tool, as shown in Fig. 17 (*a*). A long holder for side cuts is made by cutting a rectangular slot for the tool through a bar of square steel, near the end, and drilling and tapping for a setscrew in the end, as shown in (*b*).

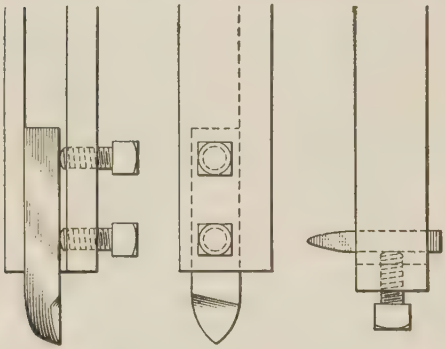

FIG. 17

16. Gang Planer Tools. — By increasing the feed to any great extent when only one tool is used, a heavy pressure is put on the tool and on the planer head; besides, the surface produced is rough and the metal is liable to be broken away where the tool leaves the work, leaving a rough edge. The gang planer tool shown in Fig. 18 offsets the objections to the single tool with heavy feed. To the shank *a* is attached an adjustable head *b* by a pin at the center of the end of the shank, so that the head may be swung when the clamping screws *c* are loosened. As the head is swung, the edges *d* of the tools *e* are offset; that is, each one stands a little to the side of the one just ahead of it. In this way all of the tools can be arranged to cut at one time, each taking a narrow cut. All of the tools *e* are ground to a gauge. When the shank *a* has been clamped in the tool block, the setscrews *f* are loosened and each tool *e* is allowed to rest on the planer table, after which the setscrews are tightened. The head is then swung until the cutting edges are set a little out of line, and is clamped by the

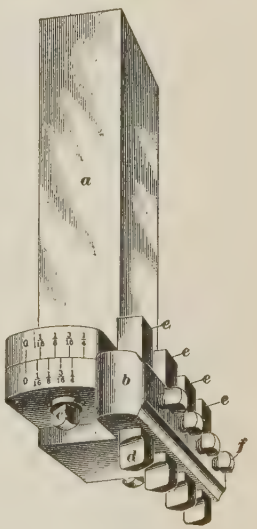

FIG. 18

screws *c*. The gang tool will then take cuts as shown in Fig. 19, each tool turning a narrow chip. At each cutting stroke, therefore, the tools take a total cut four times the cut of a single tool, yet each is able to take its share without being strained. It takes more power to turn a chip $\frac{1}{4}$ inch thick than to turn four chips $\frac{1}{16}$ inch thick; hence, the advantage of using a gang tool is that it is possible to take heavy roughing cuts, using a coarse feed without undue strain.

FIG. 19

SETTING PLANER TOOLS

17. Setting Finishing Tools.—Great care must be taken in setting finishing tools, if the best results are to be obtained. The broad-nosed finishing tool should be set so that the straight part of the cutting edge rests nearly flat on the surface of the work. The end of the cutting edge on the leading side of the tool, which is the side facing in the direction of feed of the tool, should be slightly lower than the end that follows. The exact amount cannot be measured easily, as it is only a fraction of the thickness of tissue paper. The leading end does most of the cutting, and the remainder is relieved of the work, with the result that chattering is prevented and a smooth surface is obtained. Finishing tools are first set by eye, as nearly as possible, and are lightly clamped. The planer is next started and a light scraping cut is taken at some point of the surface to be finished. Adjustments of the setting are then made as required, after which the tool is clamped firmly and set to the desired feed.

18. Spring of Planer Tools.—When the pressure of the cut comes on the tool, the latter tends to bend or spring backwards about the lowest point against which its shank is supported. For example, in Fig. 20 (*a*) and (*b*), the pressure of the cut acting against the point of the tool will tend to spring the tool backwards and cause it to swing around the point *a*. If

the point b of the tool is ahead of a vertical line $c\,d$ drawn through the point a, as in (a), then the bending backwards of the tool will cause the point b to swing down and cut deeper into the work e. But if the tool is formed and set so that its point b is

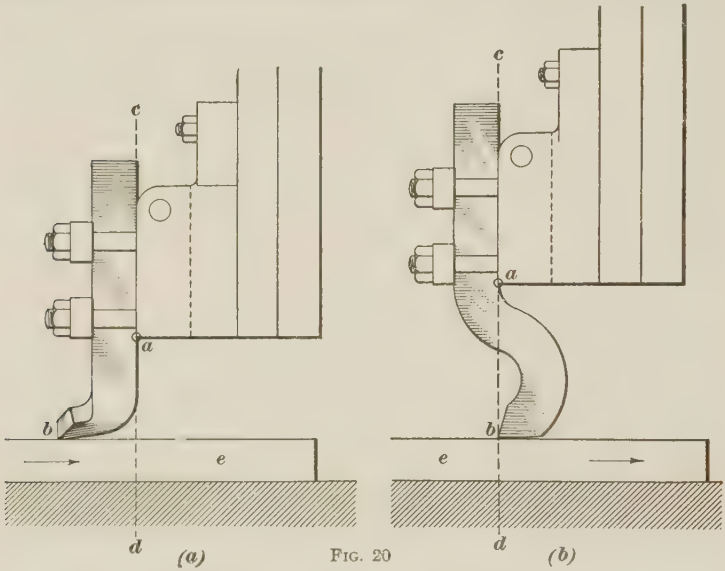

FIG. 20

on the vertical line $c\,d$ through a, as in (b), or if it is behind this line, then any bending of the tool backwards will cause the point b to swing upwards and take a lighter cut, and will thus prevent chattering.

PLANER ADJUSTMENTS

CORRECTION OF ERRORS

19. Errors in Planer Table.—The effect of the driving in of stop-pins, the pull of clamp bolts, and the careless handling of work is to peen the top of the planer table and stretch it, causing it to spring upwards at the middle. Consequently, in planing long work, the table extends over the ends of the bed and its ends drop down, so that the work produced is not true.

The table must then be trued, which may be done by taking a few light cuts across it. The first cut should not be so deep as to extend the whole length of the table; for if it is, there will be so much metal removed that the table will slowly spring back to its former shape as the cutting proceeds, and by the time the tool has been fed across, the edge at which the cut was started will be low in the middle. One or more light cuts will then be necessary to finish truing the table.

20. Sometimes it is advisable to bend and hammer the table back to about its original shape before taking the truing cut. The front end is first set even with the end of the bed and the table is lifted so that strips of cardboard $\frac{1}{8}$ inch thick can be slipped under each side of each **V** at each corner of the table. A long clamp is run across under the bed, a bolt is passed up through it and the table, and a nut is screwed on so as to force down the high part of the table. The top of the table is then hammered with a 3- or 4-pound piece of lead or Babbitt metal until it is driven down fairly level. The finishing cut will then remove only a small amount of metal. Wear and repeated truing may weaken the table so that heavy cuts cannot be taken and finishing cuts will show a wavy surface. A weak table like this should be replaced by a new one, which should be properly fitted to the old **V**'s.

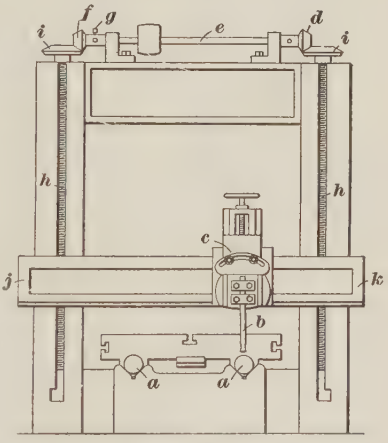

FIG. 21

21. Error in Cross-Rail.—The cross-rail must be tested to see that it is level with respect to the **V**'s, before a table is trued or any broad surface is planed. If it is not true, the work will be thicker at one edge than at the other. To test it, the table should be run back, as shown in Fig. 21, to uncover the

V's under the cross-rail. The **V**'s are wiped clean, and one of a pair of short rolls *a* of the same diameter is placed in each **V**. A square-nosed tool *b* that has previously been set flat on the table is adjusted over one roll until a feeler gauge will just pass between it and the roll. The head *c* is then moved over to the other roll and the test is repeated. When the feeler is held with the same pressure on each roll, the rail is set correctly; if not, some adjustment must be made.

22. Adjustment of Cross-Rail.—In the planer shown in Fig. 21, the pinion *d* is firmly pinned to the elevating shaft *e*, but the pinion *f* is held by a setscrew *g*. The elevating screws *h* have the same pitch and the bevel gears *i* are the same size; so, when the shaft *e* turns, both ends of the cross-rail move the same distance. If the cross-rail is found low at one end, that end must be raised. To do so, the setscrew *g* is loosened. Then, if the end *j* is low, the pinion *f* is turned so as to lift it to the same height as the end *k*, after which the setscrew *g* is tightened. If the end *k* is low, the shaft *e* is turned until the end *k* is at the height of the end *j*, and the setscrew is tightened. After making these adjustments, the rail should be raised about $\frac{1}{4}$ inch, to take up all backlash, and should be given a final test. Planers of other makes have other ways of adjusting the height of the cross-rail, and the workman should become familiar with the particular machine he is operating.

23. Sag of Planer Bed.—Long planer beds, particularly the older and lighter designs, will sag at the middle, if they are not carefully supported, and will cause long work to be planed hollow, or low at the center; or, if the sag occurs at the ends, the work will be high at the center. The straightness of the bed may be tested by placing a straightedge on the planed surface, with a slip of paper under each end and under the middle of the straightedge. The jacks or adjustable wedges that are often placed under the bed should then be tightened up or slacked off until the slips of paper are held with the same pressure.

SETTING PLANER WORK

24. Size blocks are pieces of tool steel hardened and ground to size, and marked with their thicknesses. They are usually made in sets increasing by $\frac{1}{16}$ inch. If a surface is to be planed at a certain height above another surface, as in Fig. 22, a size block *a* of the proper thickness is laid on the lower surface *b* and the tool *c* is run down until it just allows the block to slide beneath it. The tool is then set to plane the required upper surface. The size block is not so accurate as the depth gauge, but may be used more quickly.

25. Surface Gauge. – The use of the surface gauge in setting work to a line is illustrated in Fig. 23 (*a*). The line *a* is scribed on the face of the work. The pointer *b* of the gauge is set to one end of the line, the base *c* resting fairly on the table. The surface gauge is now moved along the table to the other end of the work, and it is noted whether the pointer *b* fits into the other end of the line. If it does not, the work is shifted a little and the test is repeated until the pointer touches the line fairly when at either end of the work. The line is then parallel with the table. The gauge is used as shown in (*b*) to set a surface parallel to the table. Suppose that the work *a* has two surfaces *b* and *c* that are to be set at the same height above the table. The curved pointer is set to touch the surface *b* and then the gauge is moved over to the dotted position. If the pointer does not touch the surface *c*, the work is blocked up and the testing is repeated until the pointer touches both surfaces when shifted from side to side of the work.

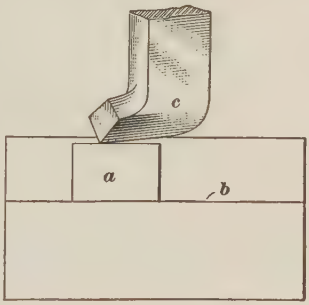

FIG. 22

26. Warping of Planed Work.—The uneven cooling of castings and forgings, and the hammering that they may receive, set up forces, called *internal stresses*, in them. These stresses are usually strongest at the surface of the work, and when one

side is planed the work is likely to warp, especially if it is long and thin. Hence, to produce the truest work all the roughing cuts should be taken before any of the finishing cuts. This will relieve most of the internal stresses and the work will assume

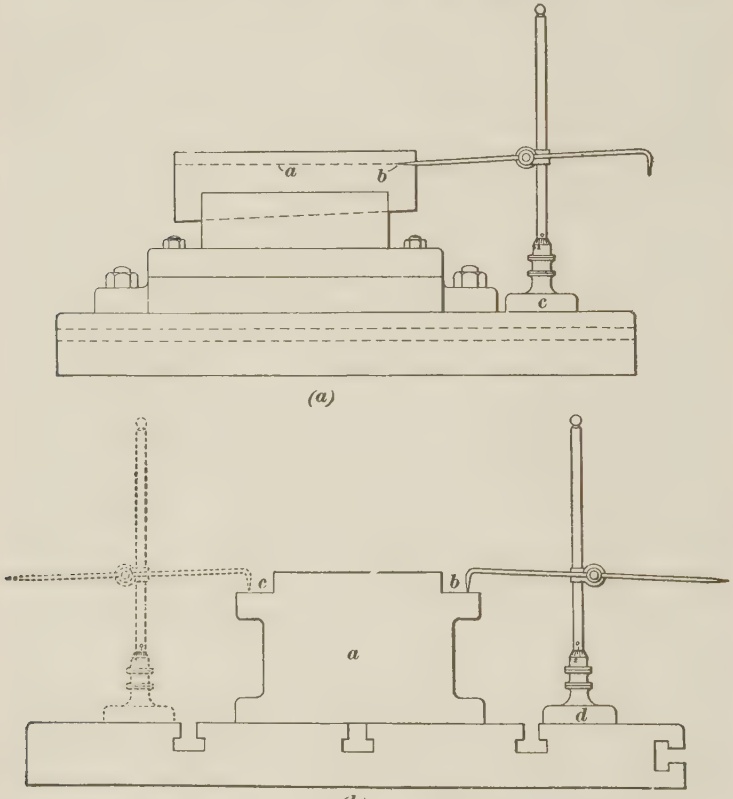

FIG. 23

its permanent shape. The light finishing cuts will true the work and will not cause enough additional warping to be noticeable.

27. Suppose that a straight casting is clamped carefully, so that when it is laid on the table it has a fair bearing, and that a cut is taken over the top so that it is straight. On

removing the clamps, the piece may spring up in the center, as shown somewhat exaggerated in Fig. 24 (*a*). Before the piece is planed, the stresses at the two sides *a* and *b* are about equal; consequently, the piece remains straight. On taking a cut over one side, as *b*, some of the stresses are relieved, and the stresses at the side *a* bend the work upwards at the center, as shown. If the piece is turned over, as shown in (*b*), and carefully clamped with pieces under the ends, so that it will not be sprung in clamping, and if a cut is now taken over the top surface *a* as deep as the cut that was taken over the lower surface *b*, it will be found upon releasing the clamps that the

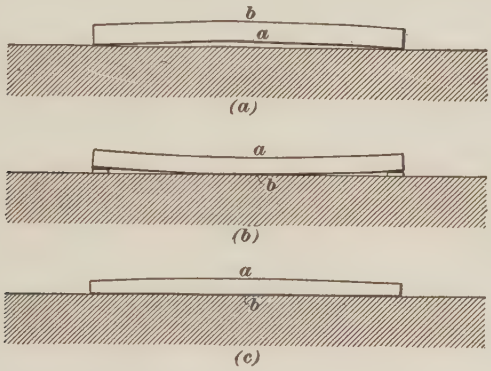

FIG. 24

work will again change its form, this time springing back to about its normal shape. The lower face *b* will again be nearly straight and the upper face *a* curved, as shown in (*c*).

28. Spring of Work in Clamping.—Another cause of untrue work is improper clamping. A very slight pressure of misplaced clamps may seriously spring the work out of shape. A casting or a forging is never true, and when it is first put on the table it rarely touches at more than three points. When correctly set, the work does not actually touch the table, but rests on packing or blocking at the various points of support. The piece shown in Fig. 25 illustrates springing due to incorrect clamping. The bottom of the piece has high spots *a* and *b* at

some distance from the ends, where the clamps are set. The pressure of the clamps will therefore spring the center of the work upwards, and when the planing is done and the clamps

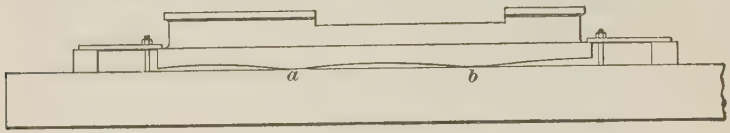

Fig. 25

are removed, the piece will spring back and be low at the middle.

29. Correct Setting of Work.—There should be a parallel block under the work at each point over which a clamp is set, as shown in Fig. 26, to prevent springing. When a piece is supported by a block under each of the four corners, it will usually be found to rock more or less on diagonally opposite corners. To prevent this rocking, strips of cardboard are added on top of the loose blocks. If there is still a tendency to rock, strips of paper of the same thickness may be added at the loose corners until the work rests solidly. The top surface is then tested with a surface gauge and if one end is low, extra blocking is used to bring it to the correct level. The clamps are finally applied, and are placed as nearly over the blocks as possible. If the work is not too large or too much out of true, pieces of cardboard may be used instead of parallel blocks. Card or

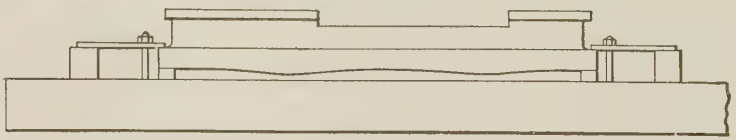

Fig. 26

paper blocking has the advantage of being easily obtained and cut into strips of suitable size. When placed under the work, they reduce vibration and tend to prevent slipping. They also show whether the work is solidly bedded. If they are held tightly, the work is correctly set; and if they are loose, it is not properly set.

30. Papering When Resetting.—After a piece has been planed and is turned over to be reset on the table, it may be sprung slightly, so that it will rock on opposite corners. A strip of tissue paper should be placed under each corner and pulled gently. If all are held with the same pressure, the work is bedded properly. If two opposite strips are loose, and the other two are tight, strips of the same thickness should be added under the loose corners until all are held equally. It is possible to get a perfect bearing in this way, if enough care is taken.

31. Sag of Long Work.—A long piece of work supported only at its ends will sag at the middle, due to its own weight and to the pressure of the tool in cutting; consequently, when it is turned over it will be high in the middle. A piece of this kind should be supported at the corners in the usual way, but should have other supports at regular distances, as shown in

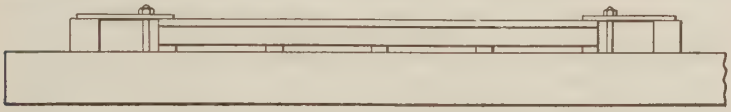

FIG. 27

Fig. 27. A slip of heavy paper should be placed on each support and pulled gently at the same time that the work is rapped lightly with a hammer directly over the support. In this way looseness of some slips may be found. It is then necessary to add slips of paper at the loose points until all are held firmly while the work is rapped with the hammer, after which the clamps are put on.

32. Straightening Long, Thin Work.—It sometimes happens, when planing long, thin work, that the piece springs after the first cut and that it will not true up when reset by the blocking method. A piece of this kind may possibly be saved by being straightened before it is reset for the cut on the other side. A short cast strip may be straightened by holding it at the ends, with the hollow surface downwards, and letting one end fall on a solid casting. It is then tested on the table, and if it is still untrue, the operation is repeated until the work is fairly straight. It is then reset and clamped and the other

side is planed. This method of straightening may be used for machine parts that are afterwards held firmly in position, but should not be used for straightedges and similar work.

CUTS AND FEEDS

33. Setting Cross-Rail and Tool for Flat Surfacing. The cross-rail should be set as close as possible to the work. If it is too high, it must be adjusted before a cut is taken. To do so, the feed is thrown out and the clamps at the back of the rail are loosened. The rail is then lowered slightly beyond the required working position, and then raised from $\frac{1}{4}$ to $\frac{1}{2}$ inch in order to take up all lost motion in the gears and the screws, after which the rail clamps are tightened.

The tool for taking a cut over a flat surface should be firmly clamped to the tool block, with the cutting edge projecting as little as possible below the block, to lessen springing. The head is then moved to bring the tool close to the work and the down-feed screw is adjusted to give the tool the desired depth of cut. After the tool has been moved up to the work and the cut is begun, the feed is thrown in.

34. Order of Cuts in Planing.—Planing is done to the best advantage by observing a certain order in taking the cuts. The main lengthwise cuts over the top and bottom of the work should be taken, and followed by such side cuts as can be made with vertical feeds. If there are some side cuts that cannot be made conveniently with the work set for planing the top or the bottom, the work is turned on edge and is fastened to an angle plate, after which the remaining side cuts are taken. Finally, the piece is swung around and set squarely across the table, so that the ends may be planed square with the top and the sides.

35. Depth of Cut and Feed.—For a roughing cut the depth of cut and the feed are made as great as the tool will stand and the planer will carry, but it must not be so great as to spring the work or break out the metal ahead of the tool

point. The power required to bend a chip depends on the thickness, rather than on the width of the chip; also, if the thickness of the chip can be reduced without reducing the feed, a greater surface can be planed in a given time. For example, Fig. 28 (*a*) shows the shape *a b d c* of a chip cut by a tool that is set vertical, the feed being equal to *a b*. If the same tool had its cutting edge at an angle of 45° and were given the same feed *a b*, it would cut a chip of the shape *a b f e*, as in (*b*). This chip has the same area as that in (*a*), so the same amount of metal would be removed in each case; but the thickness of the

FIG. 28

slanting chip is only *c d*, while that of the straight chip is *a b*, which is greater than *c d*. The chip in (*b*) will therefore take less power than that in (*a*), and the work can be done more easily and quickly.

36. Finishing Cuts on Metals.—The finishing cut on a cast-iron piece should be made with a very small depth, and with a very broad feed all in one direction, if possible, so that the tool marks will be regular. The planer should not be stopped while the surface is being planed, or there will be a line or a streak where the stop occurred. If the tool must be fed in both directions, it should be set as squarely as possible to the work and the feed in both directions should be the same. No lubricant should be put on cast iron while it is being finished, and the hands should not be laid on a cast-iron surface that is being finished; for the tool will ride over the work instead of cutting, at the spots where the surface is oily or greasy, and high spots on the finished work will result. The feeds for finishing metals other than cast iron vary according to the metal. The cuts are usually somewhat deeper than for cast iron, and the feeds are somewhat narrower.

37. Time of Feed.—The feed may take place at either end of the stroke, but it is better in most cases to have the feed take place as the return stroke commences, as the power required to operate the feed can be spared better at that time; also, the heel of the tool returns over the unplaned surface and raises the point slightly from the work. It sometimes happens, however, that the tool is heavy and the work has openings in it, or a number of pieces are openly spaced along the table so that the tool point strikes the raised front of each opening during the back stroke. In such cases it is better to have the feed take place after the planer reverses and before the cutting stroke commences. If the tool is fed just before the cut, it is best to make the stroke longer, so that the feed will be completed before the cut commences. If this is not done, and the tool feeds as it begins to cut, it will have too much side thrust, which is liable to swing the tool to one side and also to cause chattering. The feed friction is liable to slip, which reduces the size of chip taken. It is thus seen that judgment should be used in determining at which end to feed, so that the best results will be obtained.

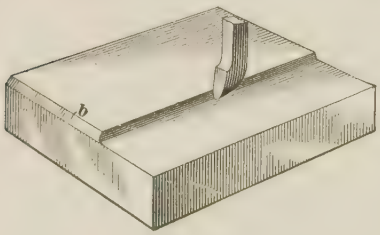

FIG. 29

38. Beveling Edge of Work.—When taking a roughing cut, the tool will break out the metal at the edge of the work just as the cut is being finished, and if the broken portion extends below the level of the surface being planed, a ragged and unsightly edge will be produced. To prevent this, the metal should be beveled off with a cold chisel to an angle of about 45°, as shown at *b*, Fig. 29, to a depth equal to the depth of the cut. It is also desirable to bevel in the same way the edge at which the cut starts, as the tool will then start cutting without shock or jar. When a finishing cut is taken, the edges should be beveled by filing rather than by chipping. The file most commonly used in planer work is a 10- or 12-inch smooth file. It may be provided with a handle and used as in ordinary bench

work, but for most classes of work the handle is removed and from $\frac{1}{2}$ to $\frac{3}{4}$ inch of the sharp end of the tang is cut off, leaving the end blunt, which prevents injury to the workman or the work. The advantage of having no handle on the file is that it may be laid flat to remove burrs or high spots that are often found on the table; also, the blunt tang finds many uses in setting and resetting work and in loosening chips packed in T slots and plug holes.

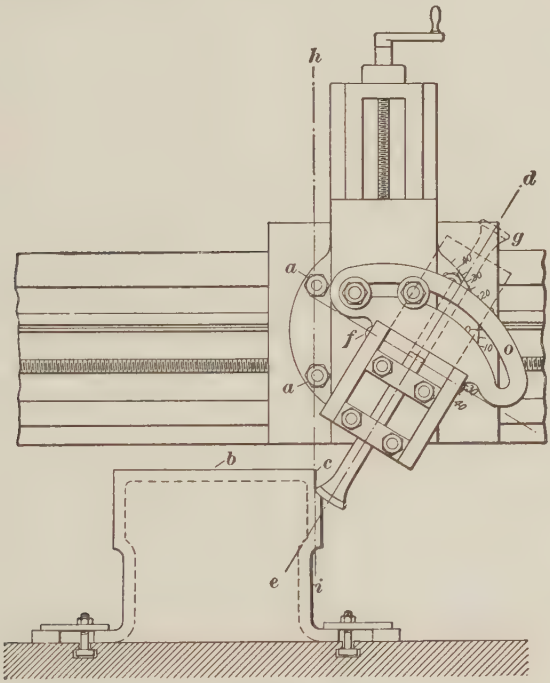

FIG. 30

39. Setting Tools for Side Cuts.—A side cut should not be so heavy as a cut on the top surface, because the tool extends farther from the tool block and therefore has more spring. If the work is so shaped that the side cut runs out at the bottom, as in Fig. 30, a round-cornered tool is used. The down-feed slide is run to the lowest point at which it will clear the work. The tool is then clamped so that its edge will reach

slightly below the lowest point of the cut, with the shank inclined away from the face to be planed. It is then run to the top and adjusted to the required position, the saddle is clamped, and the down-feed is started. The square-cornered tool is set in the same way as the round-cornered tool, except that the top of the shank is inclined more toward the work, as shown in Fig. 5 (*b*). This is done so that, when the tool reaches the corner at the bottom, the whole cutting edge will not cut at once and cause chattering. When the cut is nearly at the bottom, the tool should be moved away from the side face and set so that it scrapes the horizontal surface already planed. It should then be fed crosswise so as to form a square corner.

40. Testing Vertical Setting of Head.—When a down cut is to be made at right angles to the table, the swivel plate and the down-feed slide of the head should be tested to see that they are perpendicular to the table. The zero mark on the swivel plate should be in line with the setting mark on the saddle when the swivel plate is vertical; but it is apt to be thrown out of true in a number of ways. Hence, if the head is not set correctly, the nuts *a*, Fig. 30, are loosened and the swivel plate is turned until the graduations coincide properly and the nuts are then tightened. A finishing cut is now taken over the top surface *b*, after which a side tool is substituted and a finishing cut is taken down the side surface *c*. A try square is applied to the surfaces *b* and *c* and if they are not square with each other, the swivel plate is readjusted and another trial cut is taken down the side face. This is repeated until the side face becomes square with the top, and the head is then perpendicular to the table.

41. Effect of Swinging Apron Box.—The top of the apron box and tool block must always be inclined away from a side surface that is being planed, so that the tool will swing away from the work on the return stroke. This is shown in Fig. 30, in which the apron box is swung over until the shank of the tool slants away from the vertical face *c*, as indicated by the dotted line *d e*. If the tool is lifted, the tool block will swing on the pin *f*, and the tool will move farther and farther from the work

until, when in the dotted position shown at *g*, it will be a considerable distance from the line *h i* that denotes the vertical along the face *c*. If the apron box were inclined in the opposite direction, the tool would rise and swing into the work on the return stroke and the work or the tool, or both, would be damaged. If the tool must rise squarely, without swinging to either side, as would be the case when a slot is being planed, the apron box must be set central with the down-feed slide.

42. Direction of Feed for Side Cuts.—The tool used in a cross-rail head for making roughing side cuts always must be fed down. The reason for this is that the lines indicating the position of the cut can be drawn only on the top, or if the tool is set by measurement the rule or gauge can be applied only on the top. The tools, consequently, are made so that they must be fed down when roughing. It would also be a practical impossibility to get the tool into a position to start a cut and feed up, and if it were tried the tool would catch in the stock above during the return stroke and be dulled or shifted from position. Finishing cuts, however, if made with the rounded corner of the broad-nose squaring-down tool, shown in Fig. 5 (*a*), can be fed up, provided the tool can be set and started on the up feed from slightly below the lower edge of the surface to be finished. The feed would be about the same as that used for the down roughing cut on the same surface and the thickness of metal removed would be between $\frac{1}{64}$ and $\frac{1}{32}$ inch. The finishing cut made with a side tool, shown in Fig. 9, is very thin, as but 3 or 4 thousandths of an inch in thickness is removed and that with a coarse feed. The side tool should be set to feed down and then fed down. If a slightly greater depth of metal is required to be removed or a better finished surface is called for the feed may be reversed and the tool fed up without changing the setting of the tool sidewise. The tools used in side heads can be fed up or down, as the work is usually set to clear the table at the bottom by projecting over the side or being blocked up. It is usually better to feed the side head up as all backlash between the feed-screw and the nut is taken up by the weight of the head.

PLANER OPERATION

SQUARE PLANING IN CHUCK

43. Setting Block in Chuck.—Suppose that a rough cast-iron block is to be planed accurately square and parallel in a chuck. The truest surface is found by rocking the block on the planer table and this surface is placed against the fixed jaw *a* of the chuck, Fig. 31 (*a*). A piece of card *b* is put under each end of the block, to prevent rocking, and a piece of round

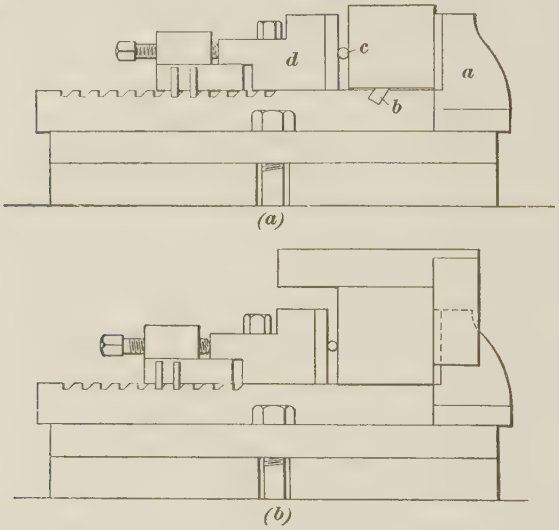

FIG. 31

iron *c* is placed between the block and the movable jaw *d*. The movable jaw is then screwed up so as to grip the block, and the round piece *c* should be raised or lowered so that the card *b* is held tightly when the jaw *d* is tightened. A hammer should not be used to drive the work down in the chuck, as it is apt to spring the piece and injure the chuck.

44. Planing of Block.—When the block is correctly set in the chuck, a roughing cut is taken across the top. This planed surface is then placed against the fixed jaw of the chuck

and the work is reset and planed. It is then turned over, and the bottom is planed, after which the remaining surfaces are roughed out. When roughing cuts have been taken all over the block, it is removed and both the work and the chuck are brushed clean. It is then reset, with strips of paper underneath it instead of pieces of card, and finishing cuts are taken over the surfaces in succession. After the second surface has been finished, the try square is applied, as in Fig. 31 (*b*), the beam being set against the first finished surface and the blade against the surface to be tested. If no light can be seen between the blade and the horizontal surface, the piece is square and the other faces may be finished to the required dimensions.

PLANING BEVELS

45. Swinging of Head.—When a beveled cut is to be made, that is, a cut at an angle of less than 90° to the surface of the table, the swivel plate is swung so that the center line of the down-feed slide is inclined at the correct angle to plane the desired bevel. In addition to this, the tool block and the apron box must always be swung so that the shank of the tool slopes away from the surface to be planed, so that it will rise from the work on the return stroke. The graduations marked on planer heads are arranged in different ways. In some cases, the graduations on the swivel plate run from zero in each direction, and this zero is opposite the zero on the saddle. In other cases, the graduations run from 90° in each direction and the 90° mark is opposite the zero on the saddle. It is necessary to be careful, therefore, when setting the head to plane a bevel, to get the swivel plate set to the correct graduation.

46. Setting Swivel Plate to Bevel Angle.—The setting of the graduated swivel plate may be illustrated by a simple example. In Fig. 32 (*a*) is shown a piece of work having bevels to be planed. The fixed side *a* has a face inclined at 55° to the vertical and 35° to the horizontal. If the planer head is graduated from zero in each direction, then, to plane the bevel of the side *a*, the swivel plate should be swung until the 55° graduation

on it is even with the zero mark on the saddle. The down-feed slide will then make an angle of 55° with the vertical and the bevel will be planed correctly. If the planer head is graduated from 90° in each direction, the swivel plate must be swung until the 35° graduation is in line with the zero mark on the

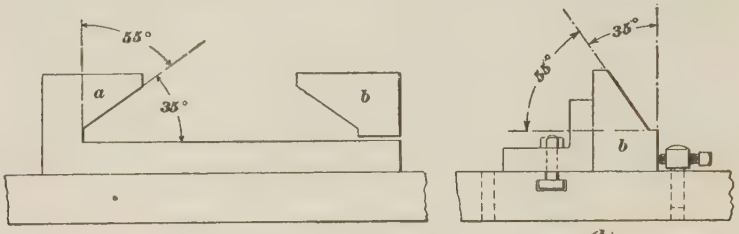

FIG. 32

saddle, in order to plane the bevel on the side *a* of the piece. The loose side *b*, called the *gib*, is to be planed at the same angle as the side *a*. It is usually set against an angle plate, as shown in (*b*). Then, if the planer head is graduated from zero, the swivel plate is swung until the 35° mark is in line with the zero on the saddle; but if it is graduated from 90°, the swivel plate is swung until the 55° mark is in line with the zero on the saddle.

T SLOTS AND UNDERCUTS

47. Planing T Slots.—The first step in planing a T slot is to cut a plain slot having a width *a*, Fig. 33, equal to that of the open part of the T slot and a depth equal to the depth of the finished slot. A tool *b* is then clamped in the tool block and is set so that its edge *c* is perpendicular to the table. The whole thickness *d* of the cutting part and the shank, at the bottom, must be less than the width *a* of the plain slot. This tool is run down until its lowest point scrapes the bottom of the slot lightly. It is then fed crosswise so as to cut one side of the

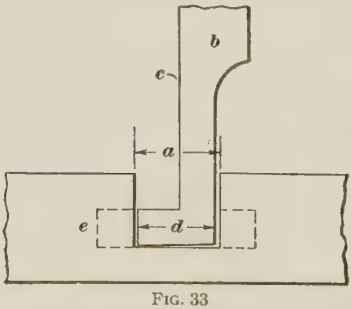

FIG. 33

T slot, as shown by the dotted lines *e*. When this is finished, a similar tool with a cutting edge facing the other way is used to cut the opposite side of the T slot. The down-feed slide is clamped while these parts of the slot are being finished; or, if no clamping device is provided, its screw is turned backwards until all backlash is taken up, so that the tool will not dig into the bottom of the slot.

48. Lifting Tool in T Slotting.—When planing the undercut sides of the T slot, the stroke is made longer at each end, and when the tool runs out at the end of the cutting stroke, it is lifted by hand while the table makes the return, to prevent

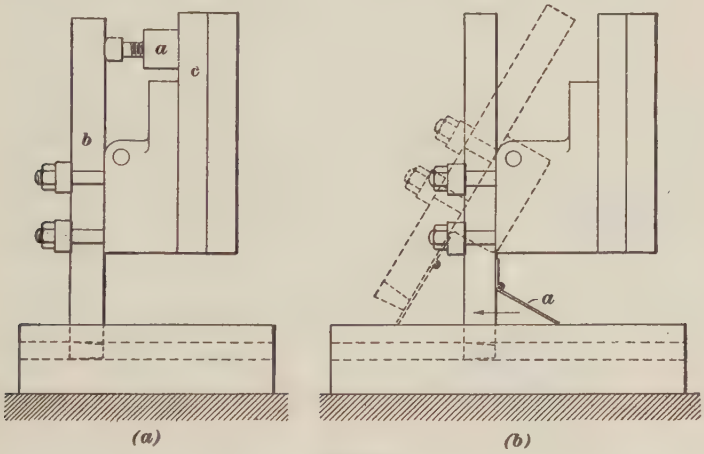

FIG. 34

injury to the tool or to the work. The feed is operated during the return stroke, and the tool is dropped for another cut as the reverse occurs. If it is inconvenient or impossible to raise the tool during the return stroke, a block or a jack *a*, Fig. 34 (*a*), may be placed between the top of the tool *b* and the down-feed slide *c* to hold the tool rigidly. When so held, the feed must occur just after the return stroke, and before starting the next cut. The tool may be lifted automatically by attaching a sheet-metal hinge to its back, as shown in (*b*). On the cutting stroke, the flap *a* drags along over the surface of the work, as indicated by the full lines. At the end of this stroke, it drops down behind

the tool, so that, on the return stroke, it rides on the work and lifts the tool, as shown by the dotted lines. At the end of the return stroke it runs off the work and drops the tool into position for another cut.

49. Undercuts.—The tool used for undercutting is similar to that used for cutting T slots, but it is larger and stronger. It is sometimes necessary to make undercuts where both ends of the work are closed. A convenient method of doing this is to put a block between the tool shank and the head as shown at *a*, Fig. 35, and then to secure a stop-screw *b* to the face of the cross-rail by means of a suitable clamp *c*. The tool is fed to the work after the dogs are set to give correct length of stroke and while it is cutting the stop-screw is brought up to the saddle. When the cut is completed the tool is quickly run out of the cut by moving the head along the cross-rail, after which the stop-screw is turned back slightly. The head *d* is fed up against the stop-screw at the beginning of the next cut, and these operations are repeated. The object of running the tool out of the cut on the return stroke is to protect its edge and insure a smoother surface on the work. This method can be used when cutting T slots that are closed at one end or that are in narrow places where it would be inconvenient or impossible to lift the tool out of the cut during the return stroke.

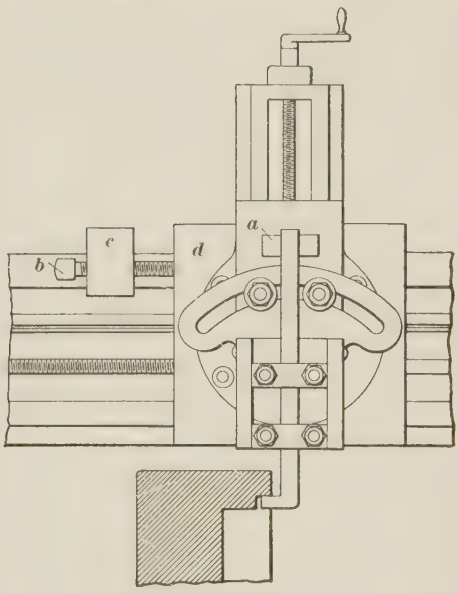

FIG. 35

PLANING LARGE WORK

50. Laying Out Engine Bed.—The first step in preparing to plane a piece of large work, such as an engine bed, is to lay out the work. The bed is placed on parallel blocks *a*, Fig. 36, on the planer table or a laying-out table, and is leveled so that the center *b* of the guides and the center *c* of the shaft in the main bearings are at the same height above the table; also, the center line *b d* through the guides and the main bearing is leveled. The centers in openings are located on strips of wood driven in the openings. The surface is then chalked and lines, as *e e*, are drawn with a surface gauge on both sides and ends of the bed, at the height of the center line *b d*. The center of the guides is located on the block driven in the cylinder end *f* and the vertical line *g g* crossing the center is drawn by the use of a square. A bottom finishing line *h*, shown dotted, is drawn at the given distance below the center line and all the details such as the cylinder end *i*, the main bearing, and the pads *j* and *k* are laid out. The top center lines *l l* and *m m* are located by a chalk line or by setting the bed on edge and using a surface gauge, after which the bed is ready for planing.

51. Planing Engine Bed.—The engine bed is placed bottom side up on the planer table, and is leveled so that the lines *e e* and *b d*, Fig. 36, are at the same height from the table, this being done by the use of a surface gauge, as shown in Fig. 37. Blocks *n* are placed under the cylinder end and the main bearing and clamps are applied above these supports. Jacks and stakes are used to prevent the work from moving, and then roughing and finishing cuts are taken over the whole bottom, to the depth indicated by the line *h*. The bed is then turned over on this finished surface and the center lines *l l* and *m m*, Fig. 36, are lined up with the direction of motion of the table, after which the pads *j* and *k* and the ends and top of the main bearing are planed. It is then turned at right angles to the table and the inside faces of the main bearing are planed. During the last operation, the end of the engine bed will extend beyond the side of the table and must be supported by a parallel piece well oiled.

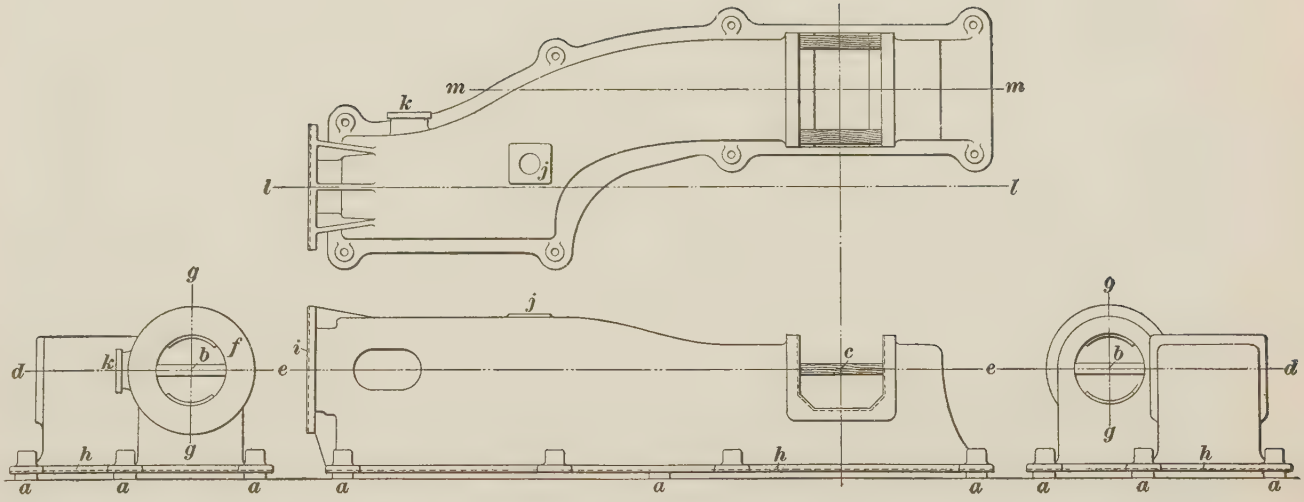

FIG. 36

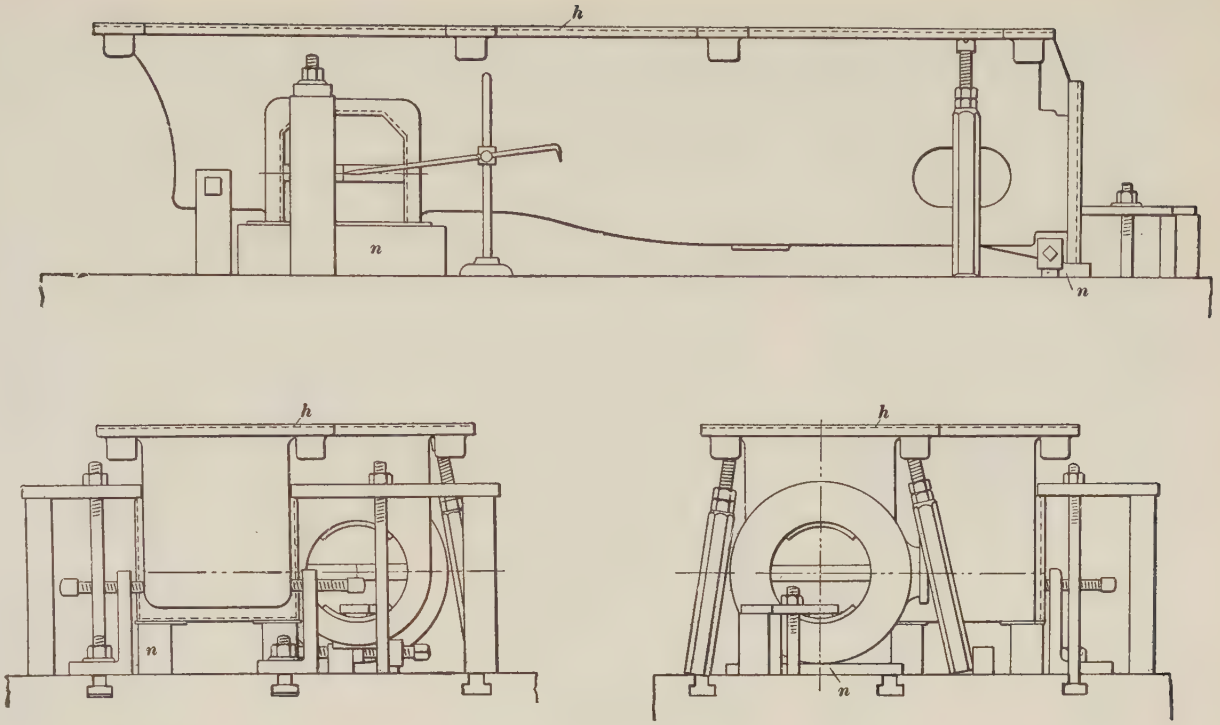

FIG. 37

52. Work too Large for Planer.—If a piece of work is much longer than the planer table, the projecting end is supported on rollers. As much as possible is planed with the piece in this position, after which the work is shifted along the table and the remainder of the piece is planed. If the work is too wide to go between the housings and is not very long, a bracket *a*, Fig. 38, is fixed to the down-feed slide and is made long enough to reach over the work when the latter is close to the housings. The tool block *b* is fixed to this bracket. This device cannot be used for very heavy cuts, as it will spring. Another way of planing work that is too wide for the housings is to use a head fixed to a column at the side of the planer. The column is supported on a floor plate that is true and level with regard to the table, and the tool may be fed horizontally or vertically across the work as it moves past with the table.

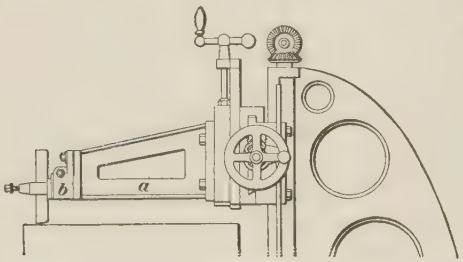

FIG. 38

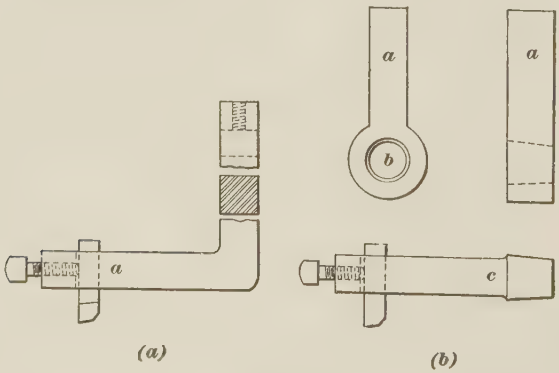

FIG. 39

53. Extension Tool Holders.—When planing the inside faces of the main bearing, Fig. 36, cutting keyways in hubs, and in similar work, extension tool holders must be used. The form

shown in Fig. 39 (*a*) consists of a piece of square steel bent to a right angle, with arms of unequal lengths and with a slot and a tapped hole at each end, so that the tool may be held at either end. The tool is held as shown at *a*. The form shown in (*b*) consists of a shank *a* with a tapered hole *b* at the lower end, into which is driven the cutter bar *c* that holds the tool.

54. Planing Curved Surfaces.—A curved surface may be planed by the rig shown in Fig. 40. A special long head *a* is pivoted at the point *b* and the distance from the point of the tool to the point *b* is made equal to the radius of the curve to be

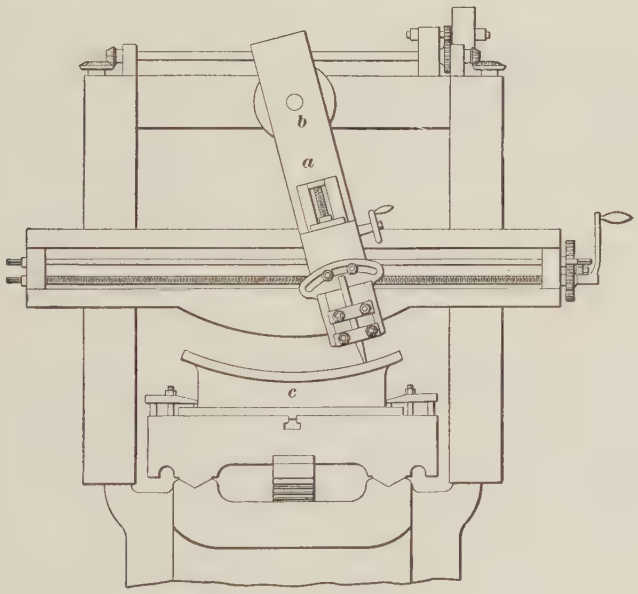

FIG. 40

planed on the work *c*. The regular down-feed slide is attached to the lower end of the special head, which is gibbed to the curved part of the special cross-rail so that it can slide freely as it swings about the center *b*. In operation, the cross-feed motion is used as in ordinary planing and the tool is adjusted to the work by the regular down feed.

55. Small curved surfaces may be planed easily by a special adjustment of the apron box. The tool is set so that the distance from its point to the center of the pin on which the apron box swings is equal to the radius of the curved surface to be planed. The tool point is then set central over the work, to

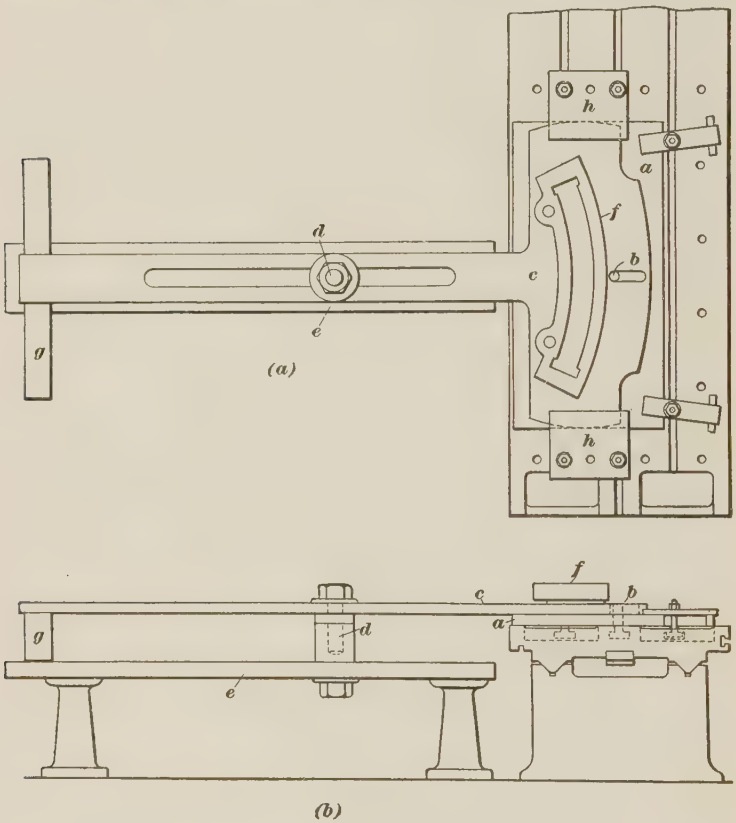

FIG. 41

bring the center of the head directly over the center of the curve to be planed. The screws holding the apron box in position are adjusted so that the apron box can be rapped over slightly with a wooden mallet to give the feed at each stroke. The cut is then started at one edge of the work and the tool is fed across by rapping the apron box. Some apron boxes have the top of

the casting over the circular slot cut with worm-gear teeth and a worm provided on the down-feed slide to do the feeding.

56. Planing Curved Side Faces.—A curved side face may be planed by the use of the rig shown in Fig. 41 (*a*) and (*b*). A flat plate *a* is clamped or bolted to the planer table and in it is fixed the stout pin *b*. On the plate *a* is a work table *c* having a long slotted arm that projects squarely beyond the table and is pivoted on a pin *d* held by the floor support *e*. The distance from the center of the pin *d* to each of the curved side faces of the work *f* is equal to the radius of the curve for that face. The outer end of the slotted arm slides freely on the support *g*. The pin *b* projects upwards through a slot in the

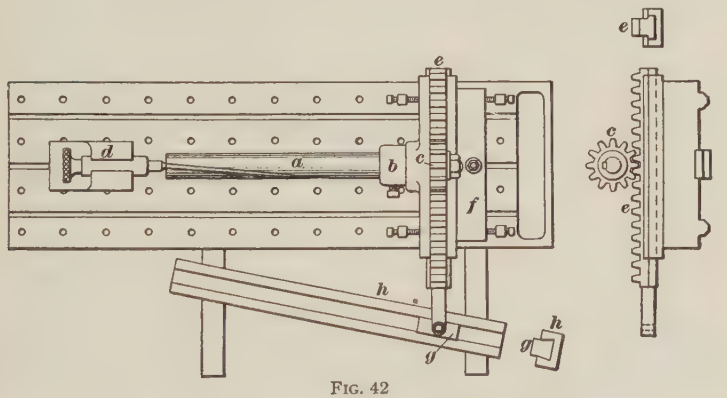

FIG. 42

work table *c*, and as it moves back and forth with the planer table, the work table is swung around the pivot *d*. At the same time, the work table has a slight motion across the plate *a*, and for this reason the slot for the pin *b* is long in a direction across the table.

57. The ends of the work table *c*, Fig. 41, are curved with a radius equal to half the length of the work table between the gooseneck clamps *h*. These clamps are bolted to the planer table and keep the plate *a* from moving lengthwise; also, their upper flanges extend over the edges of the work table, so that it may turn or slide beneath them but cannot rise off the plate *a*. The work *f* is bolted to the work table *c*, so that as the planer

table moves to and fro, the pin *b* on the plate *a* carries the work table lengthwise, and the pivoted slotted arm swings it so that the work is given the correct movement beneath the tool. A squaring-down tool is used and is fed vertically downwards.

58. Planing Spirals.—A spiral may be planed in a shaft by the arrangement shown in Fig. 42. The shaft *a* is held at one end in a chuck *b* that is firmly fixed to a pinion *c*, and at the other end the shaft is supported by the center *d*. A rack *e* meshes with the pinion and is set against a cross-parallel *f* fastened to the table. One end of the rack projects beyond the table and is pinned to a block *g* that fits in a groove in the adjustable bar *h*, which is clamped to brackets fixed to the planer bed. As the planer table moves, the block slides along the groove, and as the bar *h* is at an angle to the table, the rack *e* is given a movement

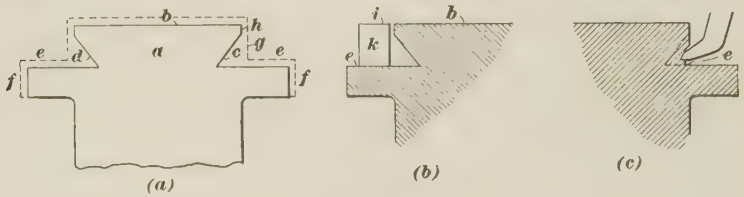

FIG. 43

across the table. This rotates the pinion *c* and the chuck *b*, and the shaft is thus given the proper motion to enable the tool to cut the spiral. The more the bar *h* is slanted away from the table, the greater will be the twist of the spiral.

59. Planing Dovetails.—If two machine parts are to be dovetailed so as to fit without adjusting gibs, the work must be done very accurately. A dovetailed part that is to fit a corresponding groove is shown at *a*, Fig. 43 (*a*). The two parts are to bear, or touch, along the surfaces *b*, *c*, and *d*. The rough casting has the shape indicated by the dotted lines, and the first operation is to take roughing cuts over the surfaces *b*, *e*, and *f*, which is usually done with a round-nosed tool having no side rake, so that it can be fed either way. The bottom surface of the casting, not shown in the illustration, is then roughed and finished and the piece is carefully reset on this finished surface,

after which the upper surfaces are finished. A square-nosed tool is used to finish the horizontal surfaces *e* and *b*; the tool may be first set to the lower surfaces *e* and both of them finished. In order to obtain the correct distance between the upper and lower surfaces *e* and *b*, it is well to use a size block *k*, as shown in (*b*). This is set on the lower surface *e*, and when the planer tool is adjusted to the upper face *i* it will be set right for finishing the top surface *b*.

60. After the horizontal surfaces *b* and *e*, Fig. 43 (*a*), have been finished, the stock must be roughed out in front of the inclined surfaces *c* and *d*, as shown in (*c*). A roughing tool of the form shown in Fig. 44 (*a*) is used. The cutting is done by the faces *a* and *b* and the tool is ground with little or no top rake and with no side rake. The planer head is set over to the required angle and the stock is removed by successive cuts, as shown in Fig. 43 (*c*), in which the dotted outline shows the required form of the groove. After all the stock has been roughed out, the portion of the lower surface *e* that is under the dovetail, and hence could not be finished by the square-nosed tool, is finished by a tool of the form shown in Fig. 44 (*b*). This tool is practically an offset square-nosed finishing tool, the cutting being done by the bottom face *a*. The top face *b* is cut away so that it can work under the bevel surface of the dovetail. The beveled surfaces *c* and *d*, Fig. 43 (*a*), are finished with an ordinary side tool using a fairly coarse feed. The work on the first beveled surface should be completed before work is begun on the second.

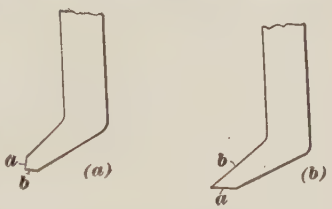

FIG. 44

61. A gauge like that shown in Fig. 45 is often used in laying out the dovetail. The two parts *a* and *b* of the gauge are fitted accurately to each other. The portion *a* is laid against the end of the work and a line is scribed around it before any undercutting is done. After the beveled surface *c*, Fig. 43 (*a*), has been completed, the head is swung verti-

cally and the side tool is used to finish the edge or corner *h*, Fig. 45, perpendicular to the top surface *c*. It is important to do this at the same setting at which the other faces are finished, as frequently the face *h* is the only surface to which the workman can refer in making measurements for fitting the work; and if the bearing surfaces become injured or worn and require redressing, the surface *h* is usually the only one by which he can set the casting accurately for refitting.

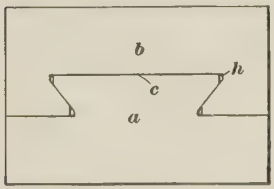

FIG. 45

62. After one side of the dovetail has been finished, the other side is planed in a similar manner, the tools used being similar to those shown in Fig. 44 (*a*) and (*b*), but forged to the opposite hand. From this it will be seen that for planing a dovetail it is necessary to have one or more roughing tools, a set of offset right-hand and left-hand tools for working under the angles, and right-hand and left-hand side tools. In planing the second side of the dovetail, the external portion *b* of the gauge shown in Fig. 45 is sometimes employed by setting one beveled edge of it against the finished edge of the work at the end and scribing inside of the other beveled edge, though usually the roughing and first finishing cuts are taken to the lines laid out with the external part *a*, and the internal part *b* is used only for testing the fit of the work during finishing. If the side *c*, Fig. 43 (*a*), is planed first, the final fitting is done on the face *d*. Sometimes, in place of fitting the work to a gauge, the final fit is made by using as a gauge one of the pieces that is to work on the slide *a*. Of course, in planing where no gib is used, no attempt should be made to make the pieces work together freely, as some stock must always be left for the fitter to remove when fitting the pieces. If the piece can be pushed on or driven on for from $\frac{1}{8}$ to $\frac{1}{4}$ inch, it can be fitted to slide freely.

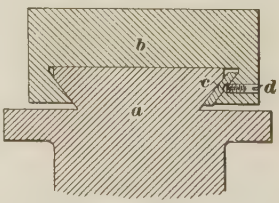

FIG. 46

63. Frequently, especially in heavy work, parts that are joined by dovetails similar to those shown in Fig. 43 (*a*) are not fitted directly to each other, but a gib is introduced, as shown at *c*, Fig. 46. The dovetailed pieces *a* and *b* are planed and fitted together in a manner similar to that already described, except that both pieces are fitted to a gauge similar to that shown in Fig. 45. After this a gib *c*, Fig. 46, is planed to fit between the pieces, and is held in place by means of setscrews, as shown at *d*. The points of the setscrews fit into recesses opposite the center of the gib. This arrangement allows considerable adjustment for taking up the wear between the surfaces on the pieces *a* and *b*; also, it simplifies the planing considerably, as the fit is already made on the gib *c*.

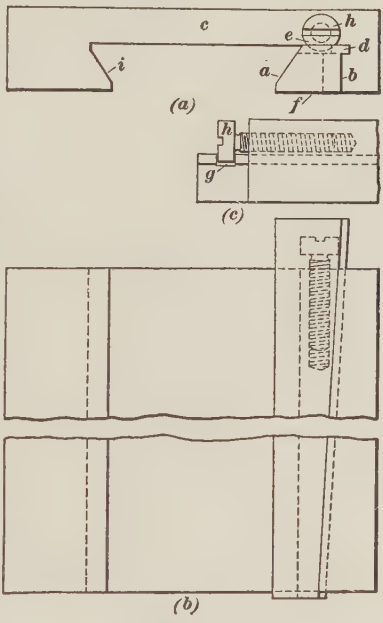

FIG. 47

64. Planing Taper Gib.—A taper gib such as is used in modern machine construction is shown in Fig. 47 (*a*), (*b*), and (*c*). The beveled surface *a* of the gib fits against the under face of the dovetail and the back face *b* is tapered, a similar taper being formed in the slide *c* as shown in (*b*). The gib has a tongue *d* that fits a corresponding groove in the slide and prevents the slide from lifting when in use. The top and bottom surfaces *e* and *f* of the gib are parallel and across the top, near the wide end, is cut a slot *g* in which fits the lower part of the head *h* of a setscrew. By screwing the adjusting screw into the slide *c*, the gib is forced in, and all backlash between the slide *c* and the dovetail is taken up. When a taper gib and a slide are required, it is best to plane an ordinary

parallel to a taper corresponding to the taper of the gib, and of the same length. This is called a *taper parallel*. It serves as a form against which the gib and the slide are held while the taper is being planed.

The slide is previously planed to shape until all surfaces except the taper surface *b* are finished. The outside edge of the slide is then set against the taper parallel, which is held against a parallel strip on the planer table, and is clamped in place. This brings the surface *b* parallel to the line of motion, and the surface *b* and the bottom of the groove for the tongue *d* are then planed to fit the back surface *b* and the tongue of the gib, or so that the gib will slide freely into place.

65. The gib is roughed out from a piece of rectangular stock, which is planed down to a thickness equal to the distance between the top and bottom faces *e* and *f*, Fig. 47 (*a*). It is then set with its top face *e* against a parallel strip or the fixed jaw of a vise and the back face *b* and the tongue *d* are planed true and square with the bottom *f*. The surface *f* of the gib is next fastened against the parallel strip with the taper parallel underneath and supporting the face *b*, and in this position the beveled surface *a* is planed, the head being set to an angle equal to 90° minus the angle at which it was set to plane the angular face *i* on the other side.

66. When the gib has been completed thus far, the slide is put in place on the cross-slide which it is to fit, and the gib is marked from them, to determine how much metal must be removed to make it enter. The bevel is roughed nearly to size and is finished by taking a number of light cuts over the bevel surface. It should be chalked with lengthwise and crosswise lines when it is being tried in place, and it should show a good bearing by having the chalk evenly rubbed off on all of the surfaces to which it must be fitted. It may be planed down until the small end comes flush with the end of the slide, or it may be left $\frac{1}{16}$ inch or more short of the end, as it will pass in farther when it is fitted. After the gib is brought to its working position, the groove for the head of the adjusting screw is marked off and cut, thus completing the gib. If a number of tapered parts like the

slide are to be planed at one time, it is usual to make as many taper parallels as there are slides to be planed at one setting.

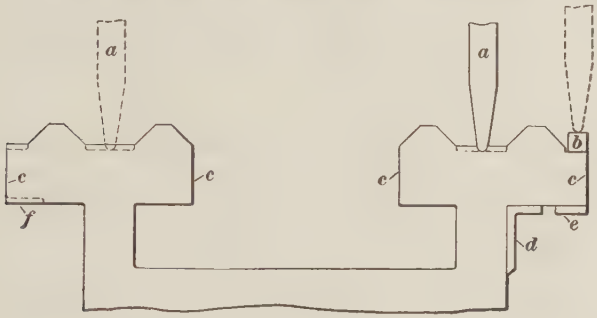

FIG. 48

67. Planing Lathe Beds.—A lathe bed that is to be planed is first placed upside down on the planer table and is leveled until the under surface, on which the V's are to be cut, is parallel with the table. It is then clamped and a roughing cut and a finishing cut are taken over the pads against which the legs are to be bolted. It is next turned over, paper strips are put under the planed pads, and it is set so that the V's are par-

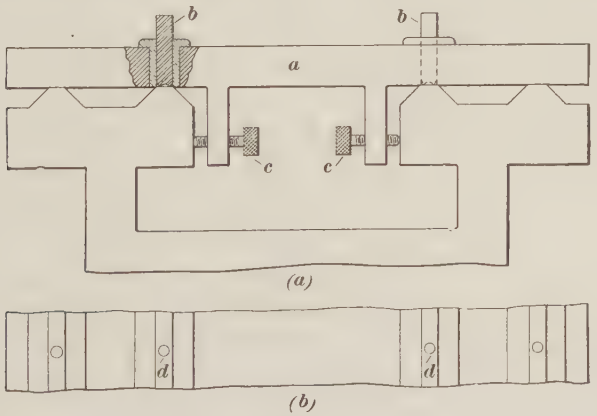

FIG. 49

allel to the line of motion of the table. The flat parts of the bed beside the V's are first roughed out with a round-nosed

tool *a*, Fig. 48, to the depth indicated by the dotted lines. A size block *b* of the proper height is used to set the tool for cutting off the tops of the V's. The same tool may be used to cut a number of grooves along the slanting faces of each V. This breaks up the scale and less work is put on the roughing tool that is used to form the V surfaces.

68. The distance between each pair of V's may be laid off by using the marking jig *a*, Fig. 49 (*a*). The two marking punches have cupped ends and are spaced at the correct dis-

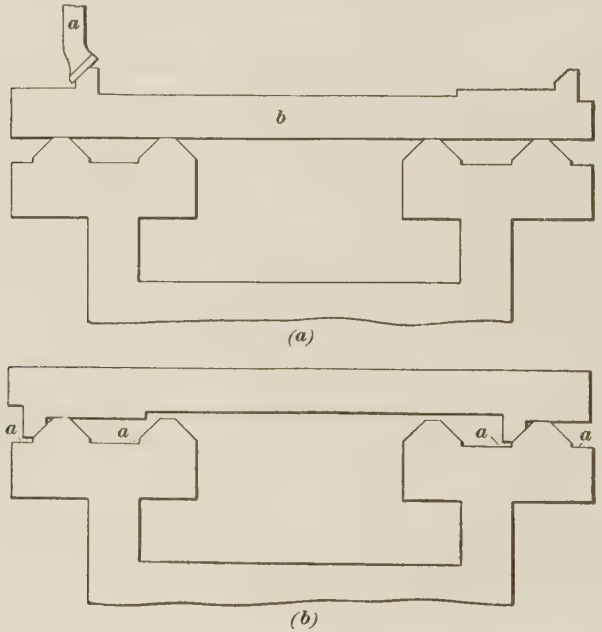

FIG. 50

tance. The jig is placed across the planed tops of the V's and adjusted by the screws *c* until the punches are central over the flat tops of the V's. Each punch is then struck with a hammer, and the cupped ends leave two circles *d* on the tops of the V's, as shown in (*b*). A similar gauge may be used to mark the other pair of V's, or one gauge may be made to mark all four.

69. The roughing tool for forming the V's is made as at *a*, Fig. 50 (*a*), but both right hand and left hand, and is set to the correct angle by the use of the V gauge *b*. It is then fed from each side until it just touches the circle *d*, Fig. 49 (*b*). After the inclined faces are planed, the spacing of the V's is

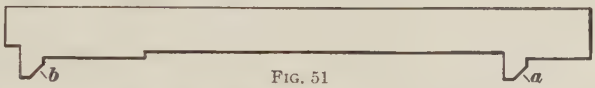

FIG. 51

tested by bringing the inclined faces of the V gauge against them, as shown in Fig. 50 (*b*). Paper strips are put between the gauge and the work to determine the accuracy of the fit. The side surfaces *c*, Fig. 48, are next squared down, and such undercuts as the rack seat *d*, the pads *e* for the lead screw and feed-rod, the seat *f* for the back gib of the carriage, and the seat for the taper attachment are planed, if they can be reached by side heads or tool holders; if not, the bed is reset on its side and they are then roughed out.

70. Gauge for Spacing V's.—The spacing of the V's on lathes and other machines must be very accurate; therefore, a gauge like that shown in Fig. 51 is used, as it will test each side of the V's separately. The gauge is finished all over, and the gauging surfaces *a* and *b* are planed at the required angle of the V's. This gauge can be tried on only one side of the V's at one time and it may be used to gauge the ways or grooves of the lathe carriage and the tailstock as well as those of the bed.

71. Finishing of Bed.—After the bed of the lathe is roughed out, it should be allowed to stand for a month to season, before it is finished. For the finishing operation, it should be papered, lined, and clamped. The top surfaces *a*, Fig. 50 (*b*), are then planed with a narrow finishing tool and the tops of the V's are planed to the correct height above the surfaces *a*. The head is then swung over to the correct angle and a side tool is set to plane down the sides of the V's. Successive cuts are taken down the

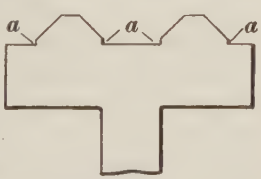

FIG. 52

inclined faces and the gauge shown in Fig. 51 is tried after each cut until slips of tissue paper between the faces of the gauge and the sides of the V's being tested are held with equal pressure. The other pair of V's is then planed with the same tool, after which the head is swung over to the opposite side and the other inclined faces are finished. The corners at the base of each V are then squared down, as shown at *a*, Fig. 52, and the work is completed by finishing those surfaces on which undercuts were made.

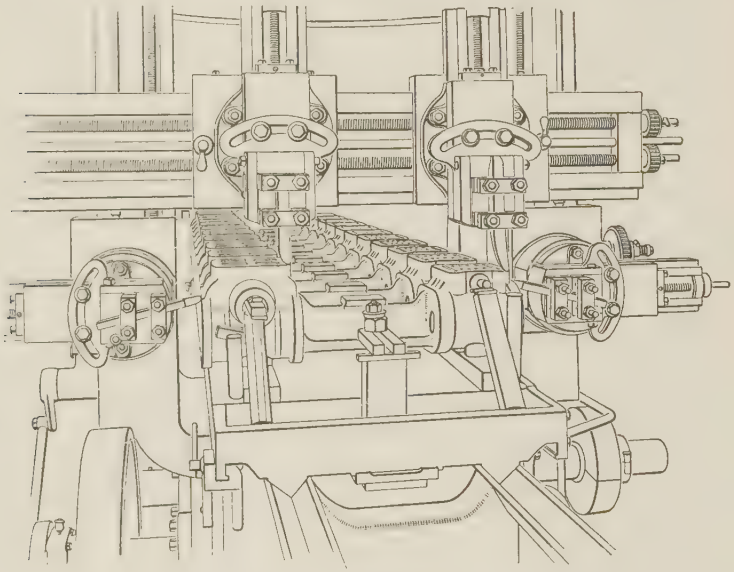

Fig. 53

72. String Planing or Gang Planing.—If a number of similar pieces are to be planed in the same way, time may be saved by arranging them in a string, or gang, on the planer table, as shown in Fig. 53, and taking continuous cuts over all. In the case illustrated, each of the eleven pump castings is carefully set and clamped in place, with as little space as possible between adjoining castings. The four heads of the planer are in use at one time. The heads on the cross-rail are being used in planing the faces of the water cylinder and the steam chest,

and the side heads are being used in planing the ends to which the covers of the steam and water cylinders are to be bolted. Each tool, therefore, is set only once.

CARE OF PLANERS

73. Lost Motion and Wear.—The various parts of the planer should always be kept adjusted so that there is no lost motion. The screws in the gibs of the down-feed slide and of the cross-rail should be kept tight, so that the slide and the planer head will have no shake or lost motion. The pawl or the ratchet of the feed-mechanism often becomes so worn that it slips or will not work, and it should be kept in good repair. The table and the cross-rail should be tested and inspected frequently to make sure that they are in condition to produce true work.

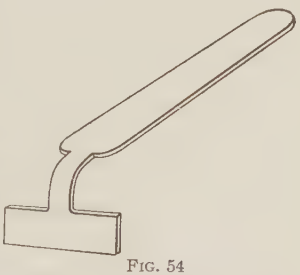

FIG. 54

74. Removal of Chips.—The chips are usually swept off the table with a brush or a broom, after the work is removed. Those that fall into the T slots and become packed there may be loosened with the blunt tang of a file and then swept out with a scraper of the form shown in Fig. 54, which has a handle several inches long and is made of sheet steel $\frac{1}{8}$ inch thick. Sometimes the chips get packed between the teeth of the bull wheel to such a depth that they cause the table to rise off the ways. The table must then be run back and the spaces between the teeth must be thoroughly cleaned.

75. Care of Planer V's.—The planer should be oiled daily, at least, with a good grade of machine oil and the ways of large planers should be oiled with cylinder oil or other heavy oil. The oiling of the ways of small planers may be done by hand, but large planers should be oiled continuously. This is usually done by casting oil pockets in the ways and placing in them rollers that are held up against the table ways by

springs. As the table moves, the rollers are turned and the oil adhering to them is carried up and spread over the ways. If the ways wear so that they fit very closely, the oil may be squeezed out by a heavy load on the table, and then they will cut each other. This action may often be prevented by cutting oil grooves across the V's at right angles to the line of motion of the table. The V's should be protected from flying chips and dust by broad boards extending out from the table over the V's in the bed. If there is a considerable length of the V's uncovered by the table while running on a short stroke, board covers are placed on the V's. The V's of old planers sometimes wear so that the bull wheel bottoms in the table rack and causes the table to ride and vibrate. This is corrected by taking the rack off and planing down its back.

76. Stopping a Belt-Driven Planer.—When a cut has been finished on the face of a piece of work, the reversing dog at the side of the table is thrown out, so that it will not act to shift the belts, and the power is shut off, after the table has started on its return stroke. The momentum of the moving parts will then carry the table beyond the position at which it should stand to begin the next operation. When the table has moved slightly beyond this position, the reversing mechanism is operated by hand, which will again change the direction of motion and bring the table to rest in the desired position, with the belts on the proper pulleys to begin a cutting stroke.

77. Lubricants for Planer Work.—Cast iron is planed dry, but a lubricant should be used when cutting wrought iron or steel, to keep the tool from becoming too hot and to produce a smooth surface. Water may be used as a lubricant, but it will rust the machine and the work. Sal soda added to the water will prevent this rusting, but will coat the work with a deposit that must be cleaned off afterwards; however, this coating is more easily removed than rust. When cutting slots in wrought iron or steel, or when making finishing cuts on steel, lard oil is a good lubricant; or, if a lubricant of less body is required, it may be made by mixing equal parts of soda water and lard oil. Kerosene may be used in planing aluminum.

SHAPER AND SLOTTER WORK

SHAPERS AND SHAPER WORK

CONSTRUCTION OF SHAPERS

FEATURES AND CLASSIFICATION

1. The **shaper** is a form of planing machine in which the work is held still while the cut is being made, and the cutting tool is pushed or pulled across it. Both the shaper and the planer are used to produce flat surfaces. The planer is the best for large work requiring great accuracy, but the shaper is best adapted for small work that requires a short stroke of the cutting tool and that must be done with rapidity and a fair degree of accuracy.

2. Classes of Shapers.—The two main classes of shapers are *column shapers* and *traveling-head shapers*, the latter being also known as *traverse shapers*. The difference between the two lies in the shape of the bed and in the way the feed is obtained. In the column shaper, the work is fed sidewise under the tool, and in the traveling-head shaper the head is fed sidewise across the work. In addition to these classes there are various special shapers that are used for special kinds of work. Column shapers may be subdivided further into *crank-driven shapers* and *geared shapers*, depending on the way of driving the ram, which is the part that carries the cutting tool.

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CRANK-DRIVEN COLUMN SHAPER

3. General Arrangement of Parts.—A crank-driven column shaper is shown in Fig. 1. The box column *a* contains the driving mechanism and on the top are the guides in which slides the ram *b*. The ram has a to-and-fro motion and at its front end carries the head *c*, to which is bolted a tool block to hold the cutting tool. The head *c* is swiveled and graduated,

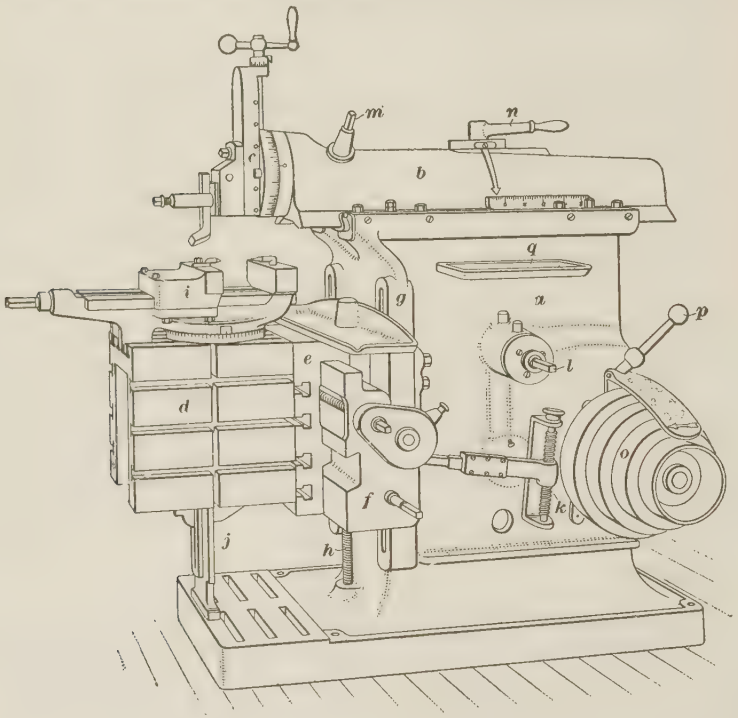


FIG. 1

and may be swung so as to make any desired angle with the top of the table *d* by which the work is supported. The table is bolted to a saddle *e* that is gibbed to the cross-rail *f* and may be moved along the rail either by hand or by automatic feed. The cross-rail is carried by a vertical slide *g*, on which it may be raised or lowered by an elevating screw *h*. The table has T

slots and plug holes, so that the work may be clamped to it or in a vise *i* held by it, and an adjustable support *j* is added to stiffen and steady it. The amount of feed at each cutting stroke of the ram is governed by the position of a slide that is adjusted by the screw *k*. The length of the stroke is altered by turning the shaft *l*, and the position of the stroke with respect to the work is adjusted by turning the shaft *m* when the clamp *n* is loosened. The shaper is driven at different speeds by shifting the belt to different steps of the cone pulley *o*, and the back gearing is thrown into action by the handle *p*. A tool shelf *q* is provided at the side.

4. Driving Mechanism.—A longitudinal section and a cross-section of one make of crank-driven shaper are shown in Fig. 2 (*a*) and (*b*), respectively. The ram *a* is moved back and forth by an arm *b* that is pivoted on a short shaft *c* at its lower end and is forked at the top to fit over pins *d* fastened in the sides of the block *e*. There is a long slot in the center of the arm *b* in which fits a block *f* that is carried by a crankpin *g*. The crankpin is held in a groove in the face of a large gear *h* and may be moved outwards or inwards along this groove by the screw *i*, which is operated through bevel gearing and spur gearing by a handle attached to the shaft *j* outside the column. When the crankpin is moved outwards, the block *f* is moved nearer the upper end of the slot in the arm *b*. As the large gear *h* turns, driven by the pinion *k* from the cone-pulley shaft, the crankpin *g* goes around with it, and the arm *b* is swung to and fro, the block *f* sliding in the slot.

5. Stroke of Ram.—The length of the stroke of the ram, Fig. 2, is shortened by moving the block *f* toward the center of the gear *h* and is lengthened by moving it in the opposite direction. After the length of the stroke has been adjusted in this way to suit the work, the position of the tool must be located. To do this, the handle *l* is turned so as to unclamp the block *e* and the hand wheel *m* is turned, thus rotating the screw *n* that fits in the block *e*. The ram is thus moved either backwards or forwards until the tool is brought to the correct position, after which the handle *l* is tightened again.

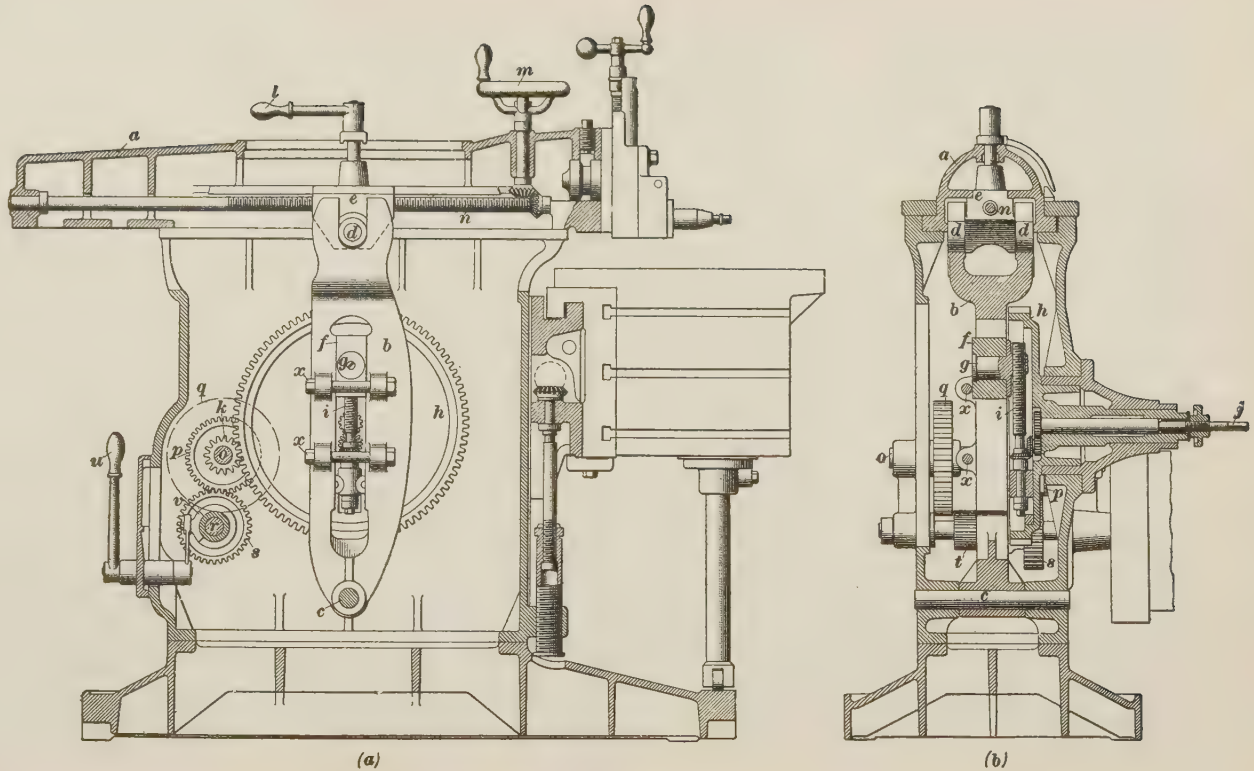


FIG. 2

6. Gearing of Crank-Driven Shaper.—The gearing of the crank-driven shaper is clearly shown in Fig. 2 (*a*) and Fig. 3. The large gear *h* meshes with the pinion *k* that is keyed to the short shaft *o*. On this same shaft, at opposite ends, are keyed the two gears *p* and *q*. The shaft *r* on which the cone pulley is fastened carries a quill, or sleeve, on which are a gear *s* and a pinion *t*, and the quill is splined so that while it must turn when the shaft *r* turns, it may be moved along the shaft in either direction. This movement is made by swinging the lever *u*, which has a short arm carrying a block *v* that fits a groove *w* in the quill. When the gear *s* is moved so as to mesh with the gear *p*, the shaper is driven at a rapid speed, and this is the usual method of driving. If a heavy cut is to be taken, the quill is moved so as to bring the pinion *t* in mesh with the gear *q*, and the shaper is then driven slowly, but powerfully, through the back gearing. When the quill is central, as shown, the ram cannot be moved by turning the cone pulley. The bolts *x* prevent the sides of the slot from springing apart when heavy cuts are being taken.

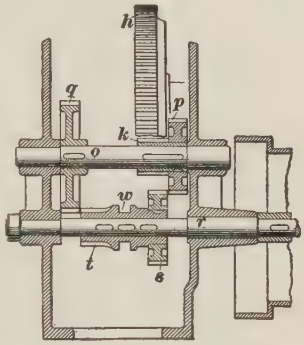


FIG. 3

7. Lever Quick-Return Motion.—The construction of the crank-driven shaper is such that the return stroke of the ram is made much more quickly than the cutting stroke. This action may be explained by use of the diagram shown in Fig. 4, in which the arm *a* is shown in its farthest forward position by full lines and in its farthest backward position by dotted lines. During one full turn of the driving gear *b* the pin *c* moves to the position *d* and back again, and the crankpin *e* in the block *f* goes through the circle *e g h i e*. While the crankpin *e* moves through the part *e g h* of the circle, the ram moves on its return stroke from *c* to *d*, and while the crankpin moves through the part *h i e* of the circle the ram moves from *d* to *c* on its cutting

stroke. As the part *e g h* of the circle is much shorter than the part *h i c*, it is plain that the time required for the return stroke

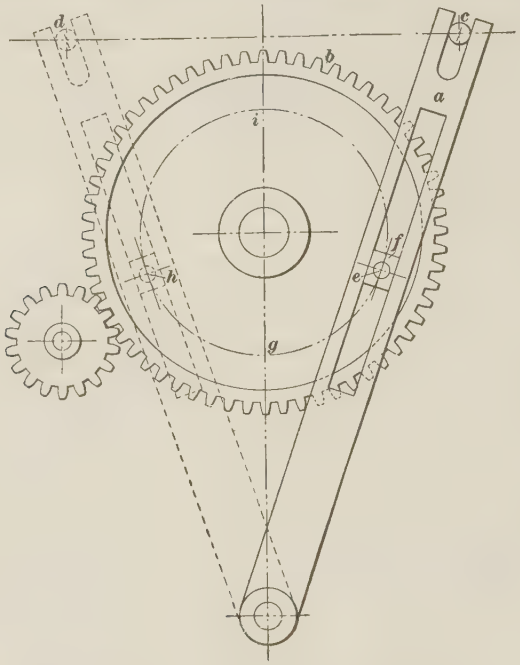


FIG. 4

is much less than that for the cutting stroke; that is, the ram moves faster on the return stroke than on the cutting stroke.

GEARED COLUMN SHAPER

8. Driving of Geared Shaper.—The geared column shaper, one form of which is shown in Fig. 5, has no slotted arm, but instead has a rack *a* fixed to the under surface of the ram. This rack meshes with a driving gear that is turned by spur gearing connected with the shaft carrying the tight pulley *b* and the loose pulleys *c* and *d*. There are two belts from the countershaft to this shaper. The driving belt, when on the pulley *b*, drives the ram on its cutting stroke, and during this time the reversing belt is on the loose pulley *c*. At the end of the cutting

stroke the belts are shifted by the arms *e* and *f*, which are operated by tappets *g* and *h* fastened to the ram. The driving belt is then moved to the loose pulley *d* and the reversing belt to the tight pulley *b*. As the reversing belt is crossed, and runs in the opposite direction from that of the driving belt, the ram is reversed and given its return stroke, at the end of which the belts are again shifted. This reversal is like that of a planer.

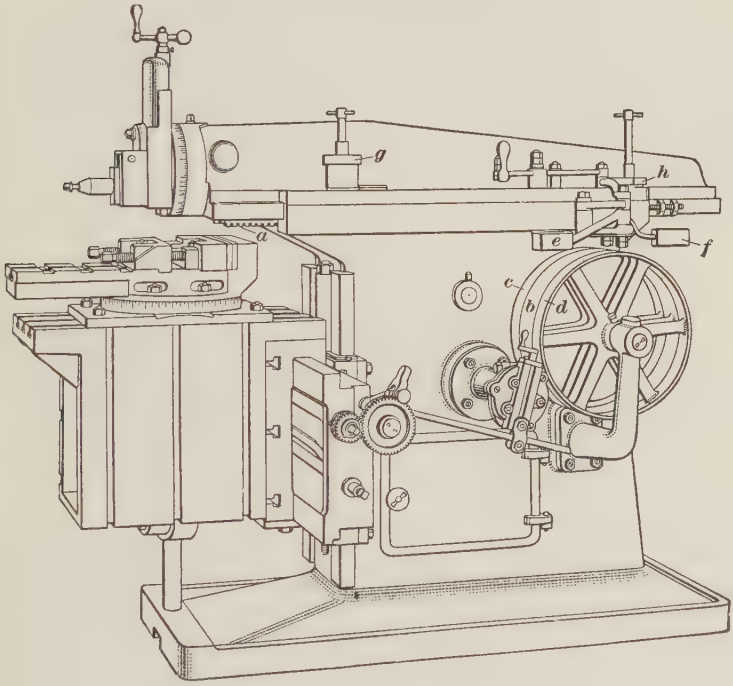


FIG. 5

9. Stroke and Quick-Return.—The length of the stroke of the geared shaper shown in Fig. 5 is increased by increasing the distance between the tappets *g* and *h* that move the belt-shifting levers, so that the ram travels farther before it is reversed. The position of the stroke with respect to the work is determined by moving the tappets along the ram to such positions as to cause reversal of the ram at the desired points. As the pulley *b* is driven by both the driving belt and the revers-

ing belt, the quick-return motion of the ram is obtained by having the reversing belt move much faster than the driving belt, which is done by making its countershaft pulley larger than that for the driving belt. The pulley *b* is then driven faster by the reversing belt, insuring a more rapid return stroke than cutting stroke.

TRAVELING-HEAD SHAPER

10. Construction and Driving.—A traveling-head shaper, one form of which is shown in Fig. 6, consists of a heavy box bed *a* to the front face of which are attached the adjustable slides *b* that carry the tables *c*. Sometimes there is only one slide carrying a single table. On the top of the bed is the ram *d*, which is carried by a saddle *e* that may be moved the whole

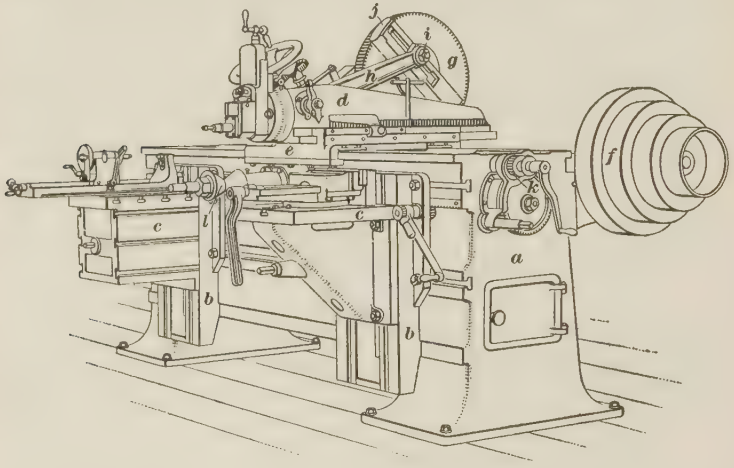


FIG. 6

length of the bed. A belt drives the cone pulley *f* and thus gives motion to a shaft that runs along the bed at the back. To this shaft is splined a pinion that meshes with the large gear *g*. A connecting-rod *h* is attached to the ram and to a pin *i* clamped in the slotted bar *j* attached to the side of the gear *g*. As the gear turns, the ram is driven back and forth. The stroke of the ram is increased by moving the pin *i* toward the outer end of the slot. The work is fastened to one or both tables,

and the tool is fed across it by moving the saddle along the bed, which may be done automatically by a feed-screw driven by the gearing *k*.

11. Whitworth Quick-Return Motion.—The traveling-head shaper is provided with the Whitworth quick-return motion, a side view of which is shown in Fig. 7. On the bed *a* is the saddle that carries the ram *b*, to which is fixed the head *c*. The pinion *k* is splined to the shaft *j*, which is driven by the cone pulley, and motion is thus given to the gear *f*. This gear *f* turns on a large pin *u* that is carried by a bracket on the frame of the saddle. The slotted arm *w* is pivoted on a pin *t* that is

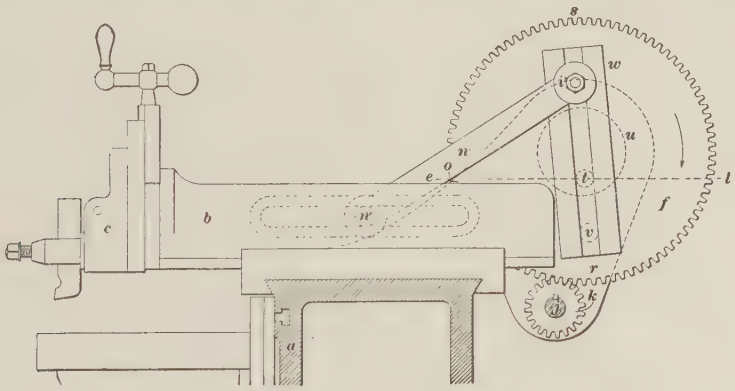


FIG. 7

set into the stationary pin *u* and on the back it has a slot in which the pin *v* may slide. The pin *v* is fast to the gear *f*, and as the gear turns, the pin *v* swings in a circle around the large pin *u*. At the same time this pin slides in the slotted arm *w* and causes it to rotate on the pin *t*, thus moving the ram *b* to and fro. The gear *f* turns at a uniform speed in the direction of the arrow, and the ram makes its cutting stroke while the pin *i* is moving below the line *e l* and its return stroke while the pin is above *e l*. The part *o s l* of the circle above the line *e l* is much longer than the part *l r o* below it, and so the return stroke is made in much less time than the forward stroke. The position of the stroke of the ram is adjusted by moving the pin *n'* in the long slot shown by dotted lines.

12. Advantages of Traveling-Head Shaper.—An advantage of the traveling-head shaper is that the tables may be used to hold the work, or they may be run out of the way or taken off and the work may be fastened to the floor in front of the ram. If the work is of peculiar shape, the two tables may be set at different heights and the work may be held by both, which is frequently advantageous. A third advantage is obtained by an attachment for planing round work. Between

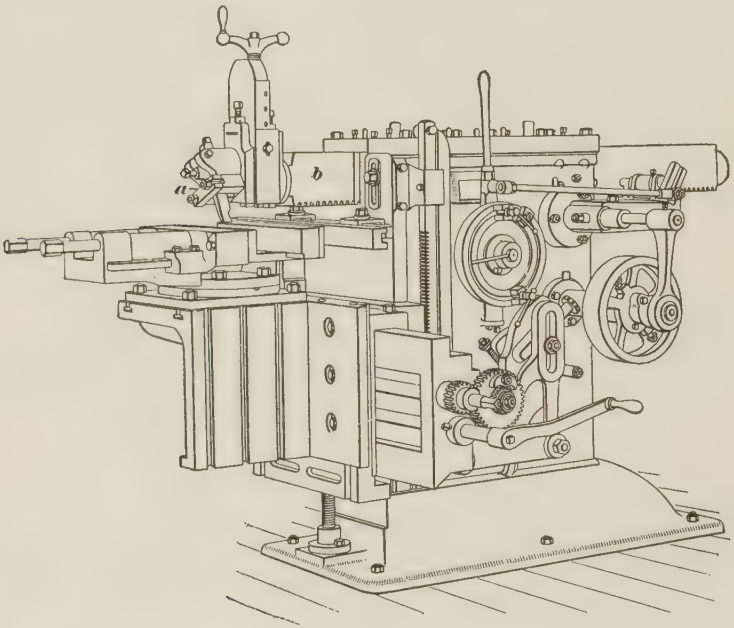


FIG. 8

the tables a hole is bored through the bed from front to rear. and in it is inserted a hollow spindle, or quill, that may be rotated by hand or by automatic feed. To the quill is clamped an arbor, shown at *l*, Fig. 6, by which the work may be held while the cutting tool is moved back and forth over it by the ram. If necessary, the arbor may be removed and long shafts of limited diameter may be passed through the quill and held while keyseats are being cut.

DRAW-CUT SHAPER

13. The draw-cut shaper shown in Fig. 8 is made and driven very much like the geared column shaper. In the geared column shaper, the cutting stroke takes place while the ram is moving outwards, away from the column. In the draw-cut shaper, however, the cutting stroke is made while the ram is moving toward the column. The apron box and the tool block *a* are reversed and attached to the head of the ram *b* in such a way that the tool points toward the column. The ram, therefore, draws or pulls the tool instead of pushing it, and the pressure of the cut forces the work toward the column; as a result, there is less danger of vibration and chattering and less error due to the spring of the table.

SHAPER OPERATIONS

CUTTING TOOLS AND SPEEDS

14. Shaper Tools.—The tools used on the shaper are of the same forms as those used on the planer, because the cutting action is the same in both machines; for, in both planer and shaper work, the shank of the tool is always at right angles to the line of motion of the tool or of the work, and the clearance does not change. About the only difference between planer tools and shaper tools is that the latter are usually the smaller.

15. Cutting Speeds for Shaper.—The proper cutting speeds for shaper tools are the same as those for planer tools. In a crank-driven shaper, the average speed of the ram varies with the length of the stroke, as, with the belt on a given step of the cone, the shaper will make a certain number of strokes per minute, whether they are long or short. Consequently, the only way to increase the average cutting speed of the crank-driven shaper is to increase the number of strokes per minute, which is done by shifting the driving belt to one of the smaller steps of the cone pulley. In geared shapers, the cutting speed does not vary with the length of stroke, but remains constant,

as is the case in planers. For this reason, geared shapers do not require cone pulleys in order to keep the cutting speed constant; however, cone pulleys are often put on geared shapers to provide different speeds for different metals.

HOLDING OF WORK

16. Shaper Vise.—The planer vise is provided with no method of adjustment on the table after the work is clamped in position; but the shaper vise is usually provided with a slide by means of which both it and the work can be adjusted. Such a vise is shown in Fig. 9. The base *a* is clamped to the shaper table. By means of the graduated circle shown at *b*, the body *c* of the vise can be set at any desired angle with the slide *e*. When set to the desired angle, the vise is clamped to the slide

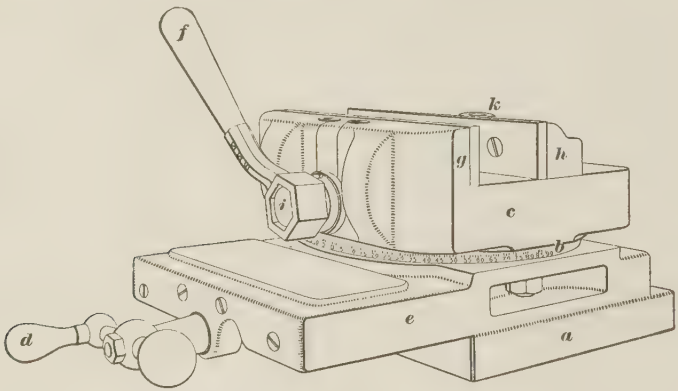


FIG. 9

by the nuts shown in the pockets at the sides. The slide can be fed back and forth across the base by a screw operated by the handle *d*. The body of the vise is provided with a fixed jaw *g* and a movable jaw *h*. The movable jaw is adjusted by means of the screw *i*, which is operated by the wrench *f*. After the movable jaw is in the desired position, it is secured by a clamp nut *k*. The jaws have removable steel faces, one of which is sometimes replaced by a V-shaped block, so as to hold cylindrical work.

17. Truing of Shaper Vise.—Most of the work done on the shaper is held in the chuck, or vise, and the methods employed for setting the work square and true, so that it may be planed square and parallel, are the same as those used in setting work in the planer vise. When used for accurate work, the shaper vise must be carefully tested and set true, as it may be out of true owing to the deflection of the table. The truing consists in lining the fixed jaw and leveling the surface on which the work rests. The fixed jaw is lined up so that a feeler gauge placed between a tool in the tool post and the face of the jaw will be held with the same pressure at every part of the face. The vise is leveled by putting pieces of cardboard or paper under the low parts of the vise or the slide until the corners of the surface of the vise that supports the work are at the same height, measured by a tool held in the tool post.

18. Truing of Shaper Table.—The shaper table must sometimes be trued. If the stroke of the ram is greater than the length of the table, the ram may be used directly to plane off the table; but if the stroke of the ram is too short, some other method must be used. The shaper should be leveled up with its back end facing the rear end of a small planer. The ram is then disconnected from its driving gear and a stiff wooden connecting-rod is used to join the ram and the planer table. The wooden rod is bolted to the slot in the top of the ram and to an angle plate on the planer table. The necessary length and position of stroke is then given to the planer table and a tool is clamped to the ram. In this way the table may be trued, the feed being operated by hand.

19. If a planer is not available for truing the shaper table as just described, a wooden cross-piece may be bolted across the top of the ram. A helper at each end of this cross-piece may then be used to push the ram back and forth. Sometimes false tables are used on shapers. A false table consists of a flat piece of cast iron having on its under side a tongue that fits the central **T** slot of the true table to which it is bolted. The top of the false table has **T** slots, **V** grooves, or ribs, in or against which the work is clamped. False tables are used when

extremely accurate work is being done on the shaper, and it is necessary to plane the working surfaces repeatedly. They are made of such length that the stroke of the shaper is great enough to allow them to be trued in place by the shaper.

20. Clamping of Work.—When work is of such a form that it cannot be held in a vise, the vise is removed and the work is fastened to the table. This is done with bolts, plugs, toe dogs, and clamps in a manner similar to that in which work is fastened on the planer table. With traveling-head shapers, very large castings or forgings that have small surfaces to be machined are frequently blocked up in front of the machine on suitable jacks and blocking, and clamped either to the table or to the front of the machine and then operated on by the tools.

TAKING CUTS

21. Cutting Keyways in Shafts.—When a keyway is to be cut in a shaft, as in Fig. 10 (*a*), it is first laid out by lines scribed to indicate the width and the depth. At the inner end of the keyway is scribed a circle having a diameter equal to the width of the keyway, and then, as shown in (*b*), a hole *a* is drilled at the center of the circle. The hole is $\frac{1}{64}$ inch larger in diameter than the width of the keyway and is drilled to the desired depth of the keyway. The shaft is then clamped in the vise, as shown in Fig. 11 (*a*), so that the distance *a* from the side of the keyway to the face of the vise jaw is the same on both sides. A splining tool of the form shown in (*b*) and of a width equal to the required width of the keyway is then put in the tool post and set flat with the

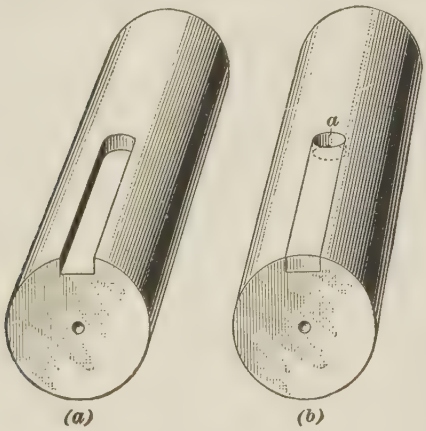


FIG. 10

top of the vise jaw, as at b in view (a). The tool is then set central with the hole drilled at the end of the keyway, as at c, the ram is adjusted to give the proper stroke, and the tool is

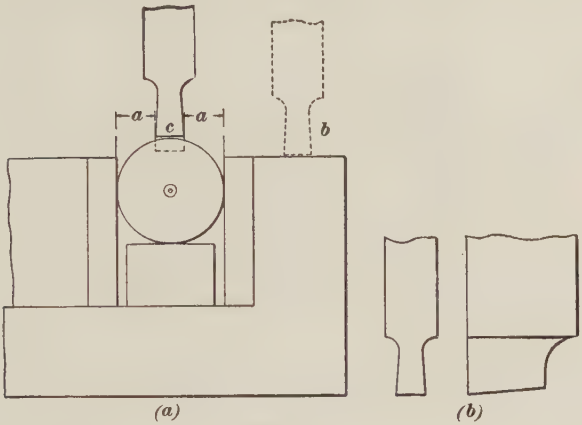


FIG. 11

fed down until the keyway is cut to the proper depth. The cutting stroke is made toward the drilled hole and oil is used to give a smooth cut.

22. If the keyway does not extend to the end of the shaft, as in Fig. 10 (a), but is cut at some point near the middle, so that it begins and ends in the solid shaft, a different method is

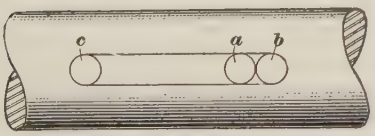


FIG. 12

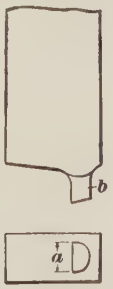


FIG. 13

followed. The length and width of the keyway are laid out, as shown in Fig. 12, and at the end where the cut is to begin a pair of holes a and b are drilled, close together. These holes are $\frac{1}{64}$

inch larger than the width of the keyway and as deep as the keyway is to be. The metal between them is then chipped out. A single hole *c* of the same size and depth is drilled at the other end of the keyway. A tool of the underhung type, as shown in Fig. 13, is then set central and the keyway is cut to the desired depth. The width *a* of the tool is equal to the width of the keyway and the part *b* is dropped into the slot chipped out between the holes *a* and *b*, Fig. 12, at the beginning of the cut. The hole *c* at the end of the cut allows the chips to be broken off cleanly and prevents them from gathering and clogging at this point.

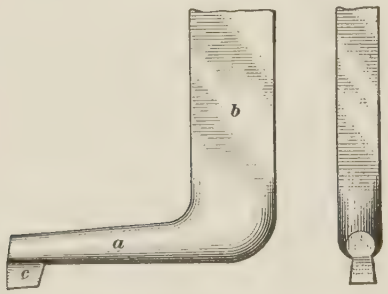


FIG. 14

23. Cutting Internal Keyways.—If the keyway is inside the hub of a gear, or similarly situated, it is necessary to cut it with an extension tool, such as that shown in Fig. 14. The extension *a* from the shank *b* carries the cutting part *c* of the

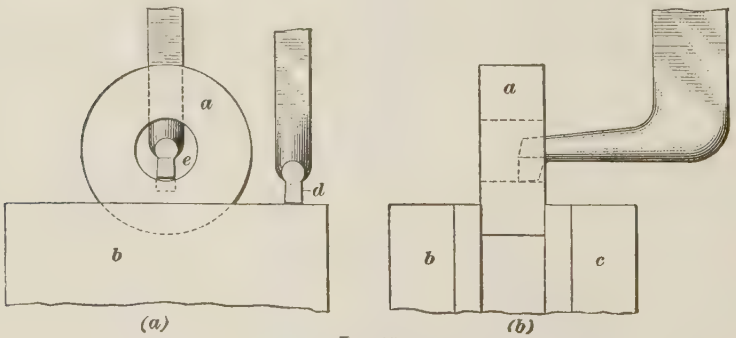


FIG. 15

tool. The method of cutting a keyway in a gear blank is shown in Fig. 15 (*a*) and (*b*). The gear blank *a* is firmly clamped in the jaws *b* and *c* of the vise, and the tool is set on the top of the jaw, as at *d*, and adjusted so that its cutting edge is level.

It is then clamped tightly in the tool post and moved to the hole *e* in the gear blank, where it is set central. This is done by lowering it and moving it from side to side until both corners of the cutting edge touch the bottom of the hole. The shaper is then started and the keyway is cut to the proper depth. Sometimes the extension tool tends to spring away from the cut, especially if the keyway is long. In such a case, a bar about 2 feet long may be placed between the top of the tool shank and the apron box. Then, by pulling on the end of this bar during the cutting stroke, the tool may be held to its work.

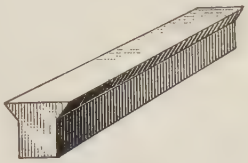


FIG. 16

24. Planing Dovetailed Keys.—Keys are often made dovetailed, as shown in Fig. 16. The method of planing a key of this form is shown in Fig. 17 (*a*) and (*b*). The rough stock *a* from which the key is to be planed is set on a thin parallel *b* and clamped between the vise jaws *c* and *d*, as shown in (*a*). A cut is then taken over the top, as indicated by the dotted horizontal line, after which side cuts are taken, as shown by the dotted

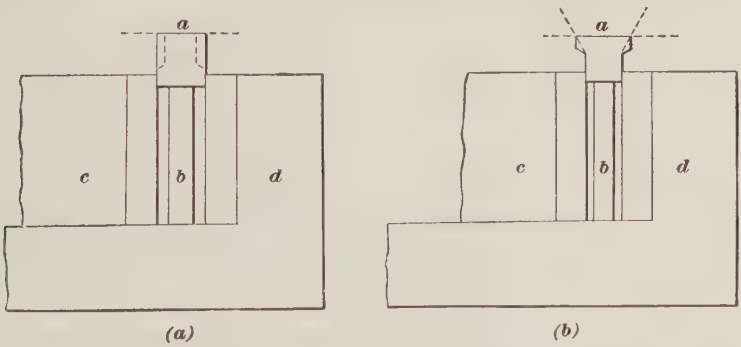


FIG. 17

vertical lines, thus finishing the square body of the key. The piece is then turned over and reset, as in (*b*), and a light cut is taken across the top, to bring the key to the required thickness from top to bottom. The head is next set over, first in one direction and then in the other, and the sides are beveled to an

angle of 10° or 15°, as shown by the sloping dotted lines, and the key completed.

25. Cutting Dovetailed Keyways.—The method of planing a dovetailed keyway may be understood by referring to Fig. 18. The bevel-gear blank shown in (*a*) has a long sleeve *a* through which a hole *b* is bored, and a dovetailed keyway is to be cut inside this sleeve. The first step is to drill a hole *c* at the point where the keyway is to end. The piece is then clamped in V blocks, as shown in (*b*), so that the hole *c* comes central at the bottom. An ordinary extension keyway tool is next set central with the hole and the keyway is cut to the

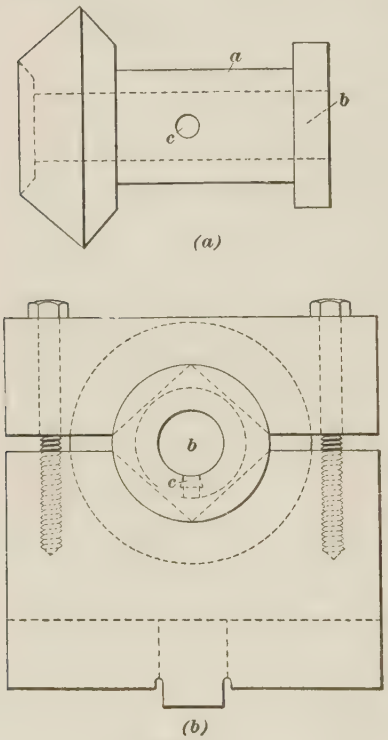


FIG. 18

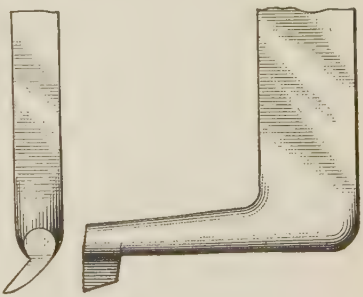


FIG. 19

proper depth. The head is now swung over, an extension tool like that shown in Fig. 19 is put in the tool post, and two or three cuts are taken to complete one beveled side, after which the head is swung in the opposite direction and a similar tool of the other hand is used to finish the other side of the keyway. The last side should be finished with light cuts and the key should be tried in the keyway until it is a tight driving fit.

The sides of the finished keyway are shown by slanting dotted lines in Fig. 18 (*b*).

26. Gauges for Keys and Keyways.—Gauges should be used to test all keys, keyways, and tools for cutting keyways, so that the work may be kept to standard sizes. A gauge for testing the width of a key or of a keyway tool is shown in Fig. 20. It consists of a steel bar of convenient size, in one edge of which are cut slots of different widths, corresponding to various standard keyways. The width of each slot is stamped beneath it. Gauges for larger keyways are made as shown in Fig. 21 (*a*) and (*b*), in which one rectangular piece *a* is made a tight hand forcing fit in the slot in the piece *b*. The size is stamped on each piece. In the best grades these gauges are of tool steel hardened and ground; but if used with care they may be of unhardened tool steel or of case-hardened soft steel.

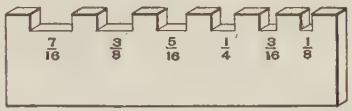
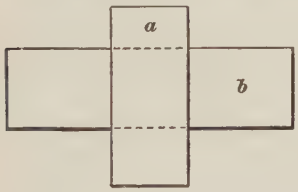
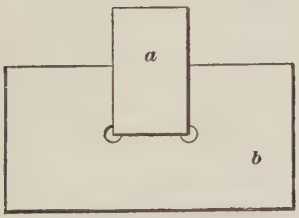


FIG. 20



(*a*)



(*b*)

FIG. 21

27. Cutting to a Shoulder. Suppose that it is necessary to take a cut over the piece of work shown in Fig. 22, and that the surface *e* is to be partly removed up to the line *A B*, as indicated by the dotted lines. Before this cut can be taken on the shaper it will be necessary to cut a groove at *A B* equal in depth to the amount to be removed. This groove can be cut with a cold chisel and a hammer or by first drilling a hole at *a* and then cutting the groove on the shaper with a parting tool. The part of the surface *e* indicated by dotted lines can then be planed away easily. In castings, when it is known that such cuts as these are to be taken, much work can be saved by coring out a space where the cut is to end.

This saves the time required to cut a groove with the chisel or by planing.

28. Clamping Work to Saddle.—Work that is too high to be placed on the shaper table, or work that cannot be clamped to the table on account of its shape, can frequently be clamped to the saddle. An example of this is shown in Fig. 23, in which a pair of legs for a lathe are clamped in position for shaping the upper surface. The table and the vise are removed and the work *a* is secured to the saddle by bolts and blocking. This method

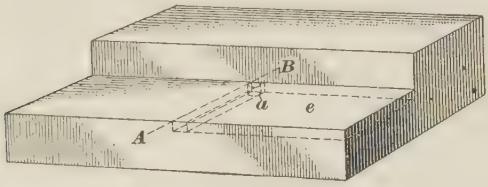


FIG. 22

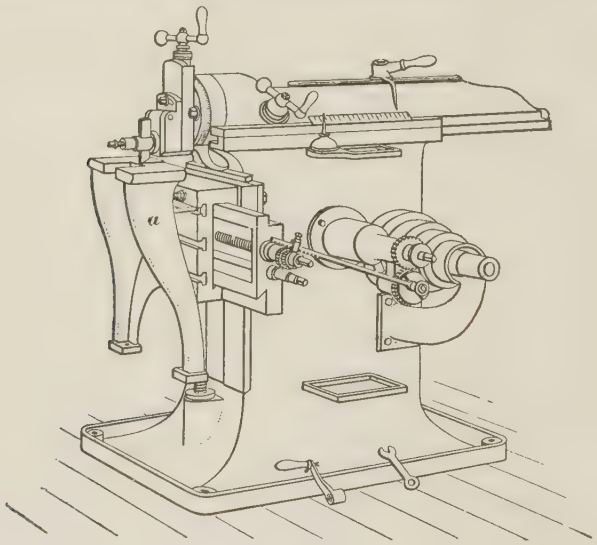


FIG. 23

of holding work is similar to attaching it to an angle plate fastened to a planer table.

29. When work is clamped against the front of the saddle, the top surface may easily be lined to the ram by means of a tool

fixed in the tool post, as shown in Fig. 23. The tool is clamped firmly and is fed down, while the machine is running, until it just touches the top of the work near one side. The tool is raised during the forward stroke and held down during the return stroke, and the rubbing of the tool point on the face of the work shows whether the work is set correctly; for, when it is correctly set, the tool point will bear with the same pressure at the middle and at the edges of the surface of the work.

30. Equal Spacing on Shaper.—The shaper may be used to cut a series of slots equally spaced, as, for example, in cutting gear-teeth in a rack. The work in which the slots are to be cut is clamped at right angles to the line of motion of the ram and a tool that will give the proper shape of slot is set in the tool post. The spacing is done by turning the feed-screw, using the graduated collar on the end of the screw as an index plate to indicate the number of turns. The rule to be used is as follows:

Rule.—*To find the number of turns that must be given to the feed-screw to give a desired equal spacing of slots, multiply the desired spacing, in inches, by the number of threads per inch on the feed-screw.*

Example.—A shaper feed-screw has 4 threads per inch and at its end is a graduated collar having 100 divisions. How many turns must be given to the screw to space equal distances of .65 inch on the work?

Solution.—Applying the rule, the required number of turns is

$$.65 \times 4 = 2.60. \quad \text{Ans.}$$

As $2.60 = 2\frac{60}{100}$, the feed-screw is given two complete turns and $\frac{60}{100}$ turn more, the latter being done by moving 60 of the 100 divisions past the zero mark.

31. Spring of Table and Work.—The spring of the work may be due to the spring of the table by which it is supported and is one of the causes of error in shaper work; also, if the gibs holding the saddle to the cross-rail are loose, the spring will be increased. The pressure of the cutting tool, as it is forced through the work, tends to spring the work still farther from the ram and increases the error.

32. Limit of Stroke of Shaper.—The ram of the shaper has a tendency to spring upwards, due to the pressure of the cut and looseness of the guides in which the ram slides; therefore, the average stroke is only about 12 to 18 inches, although large shapers with heavy rams are built to give much longer strokes. The longer the stroke, and the farther the tool moves away from the column, the greater is the tendency to spring; hence, the work should be set as close as possible to the column.

SLOTTERS AND SLOTTER WORK

CONSTRUCTION OF SLOTTERS

33. The **slotter,** or slotting machine, is very much like the shaper but in the slotter the ram moves up and down in a vertical direction; whereas, in a shaper, it moves horizontally. The slotter is used for finishing flat or curved surfaces at right angles to a horizontal surface of the work. It derives its name from the fact that it was originally intended for cutting slots or keyways in gears or pulleys, but it is used for a large variety of work, where it is desired to produce vertical, flat, or curved surfaces.

34. Arrangement of Slotter.—One form of slotter is shown in Fig. 24. It consists of a rigid frame M carrying a table F on which the work is held, and a ram A to which is fixed the head L that carries the tool. The ram is driven at different speeds from the cone pulley E through the spur gear N and the crank-disk B. In the slot in the crank-disk is an adjustable pin O that is connected with the ram pin P by the connecting-rod C. The turning of the crank-disk thus gives the ram an up-and-down motion. The length of the stroke is altered by moving the pin O in the slot in the crank-disk and the position of the stroke is changed by adjusting the pin P in the slot in the ram. A counterweight D is hung on one end of a lever pivoted above the frame, and the other end of the lever is connected with the pin P. The weight D thus helps to lift the ram on its upward stroke.

35. The table of the slotter, Fig. 24, is mounted on a saddle carried by a carriage, so that it can be moved either along the ways on the frame *M* or at right angles to these ways. Motion along the ways is given by turning the handle *I*. The table may also be rotated by turning the handle *H*, which turns a worm meshing with the teeth *Q* on the edge of the table. The

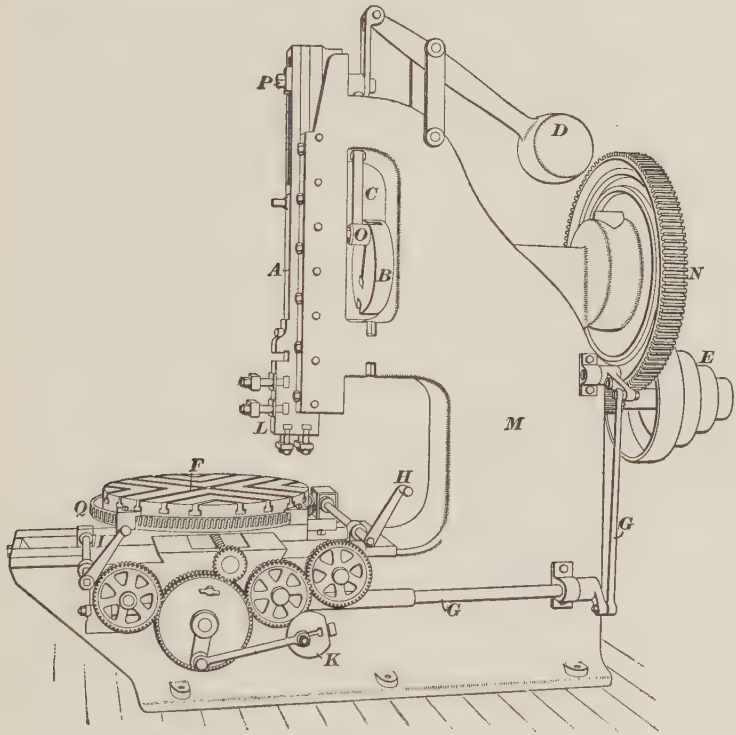


FIG. 24

feed is given to the table from the gear *N* through the rod and the shaft *G* to the gearing on the front of the carriage. The amount of feed is adjusted by moving the pin in the slot in the disk *K*. The head of the ram carries two sets of tool clamps, which provide for fastening tools in two different positions at right angles to each other. The upward, or return, stroke of the ram is made more rapidly than the downward, or cutting,

stroke, by the use of a Whitworth quick-return motion similar to that on the traveling-head shaper.

36. Motor Drive for Slotter.—The method of using an electric motor to drive a slotter is shown in Fig. 25. The motor *a* is mounted rigidly on the side of the main frame *b* and drives the gear *c*. The shaft *d* may be moved endwise by the lever *e*, operated from the opposite side of the frame, and thus cause any one of a series of gears *f* of different sizes to be driven from the gear *c*. In this way the main gear *g* may be driven at several different speeds, and the cutting speed may be varied accordingly.

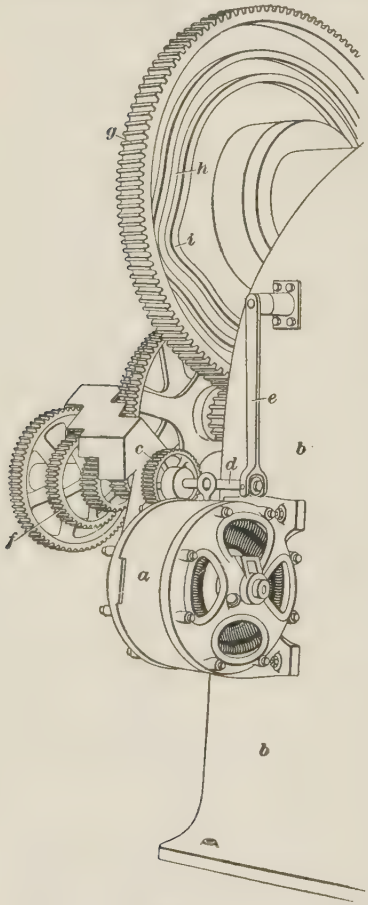


FIG. 25

37. Feed of Slotter.—As the work is moved to the tool in the slotter the feed must take place while the tool is at the top of its travel, before the beginning of the cutting stroke, and while the tool is clear of the work; consequently, the feed-gearing must have a rapid motion in order to accomplish this. Fig. 25 shows a method of obtaining a rapid feed-motion. On the inner side of the main gear *g* is formed a slot *h*, in which is a small roller on an arm connected with the rod *G*, Fig. 24. The slot is almost a complete circle, but at *i*, Fig. 25, there is a sudden outward and inward bend. During the greater part of the turn of the gear *g*, therefore, the roller is not moved; but when

the bend *i* is reached a quick motion outwards and inwards is given to the roller and this motion is transmitted to the feed-gearing on the front of the carriage. By arranging this gearing properly, a rotary, a crosswise, or a lengthwise motion may be given to the table.

38. Portable Slotters and Shapers.—It often happens that it is inconvenient to take a piece of work to the machine, or that a suitable machine for the work is not available. In such cases portable slotters and shapers are of value, as they may be carried to the work and fixed to it. They are therefore very useful in doing repair work, when the work is not moved. Again, in many shops there are special floors constructed to act as the foundations of the tools and as work tables. A deep bed of concrete is first put down and on this is placed a heavy cast-iron floor, accurately planed and leveled, and provided with T slots. The work may be placed at any convenient point on this floor, and a portable tool may be brought to it.

SLOTTER OPERATION

39. Setting Slotter Work.—Slotter work should be laid out so that the outline of the part to be cut away appears plainly on the top surface. Lines may also be placed on the sides to insure that the work will be cut square or at the correct angle. To set the work, parallel blocks or strips must be placed under it, as shown at *c*, Fig. 26, to lift it far enough above the table to allow the tool to travel to the lower end of the cut without touching the table. Clamps should be applied directly over the points of support, and the work must be in such position that the line *A B* denoting the surface to be planed is at right angles to the table. This should be tested with a square.

40. After the clamps are tightened, a pointed tool or a scriber is clamped in the tool post and the work is moved, by moving the carriage and the saddle, so that the straight line to be worked to comes under the point of the tool or scriber.

The table is then adjusted so that, as the carriage or the saddle is moved, the pointer will follow the line on the top surface of the work. If a curved surface is to be machined, the work is first located by the combined movements of the carriage and saddle and is then adjusted so that the curved line will exactly

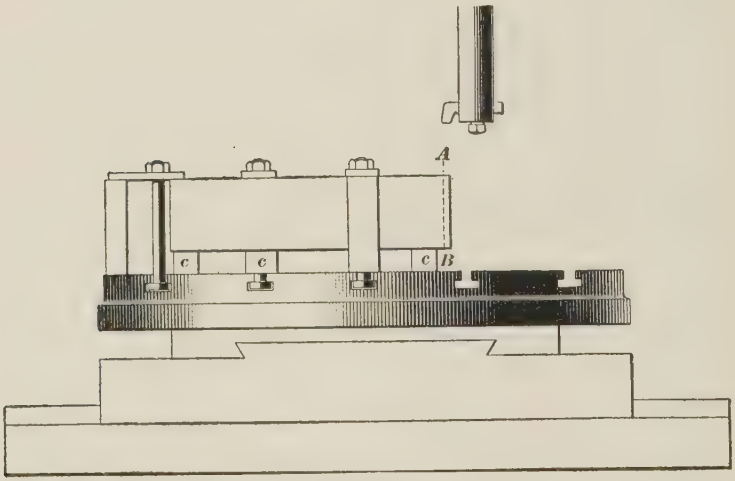


FIG. 26

follow the pointer when the table is rotated. The work is then set correctly and ready for the cutting operation. Bolts, pins, angle plates, and special holding devices may be used for holding work on the slotter table in the same way that they are used on the planer or the shaper table.

41. Setting Slotter Ram and Tool.—A stroke long enough to suit the work must first be given to the ram. This is accomplished by adjusting the pin in the slot in the crank-disk. Next, the position of the stroke must be adjusted by means of the pin at the upper end of the connecting-rod and the slot in the ram. The ram is now moved to the lowest point of its travel and the tool is clamped in it so that the cutting edge extends just below the lower edge of the work. This method of setting gives great stiffness, as the tool projects so little below the ram.

42. Cutting Circular Surfaces.—When circular surfaces are to be cut on the slotter, the work must be set so that its axis coincides with the axis of rotation of the table. For instance, if a cylindrical surface having a radius of 10 inches is to be finished in the slotter, the work must be set so that the center from which the radius is measured is at the center of the table, and the table must be adjusted so that the point of the tool is at a distance of 10 inches from the center. The feeding is done by rotating the table slightly after each down stroke of the ram.

To aid in setting work having cylindrical surfaces, concentric circles are usually marked on the table, and may be used as guides. An arbor may be fitted in the center hole of the table and the position of the work may be measured from it; or, the work may be placed on the arbor, in case the surfaces to be machined are concentric with the hole in the table. In either case, after the work is set, it is best to revolve it past the point of the tool to be sure that it is correctly set. This applies to internal as well as external cylindrical surfaces.

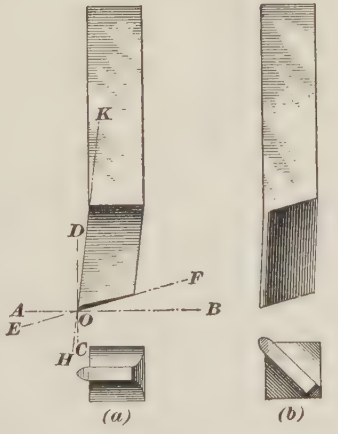


Fig. 27

43. Slotter Tools.—Some of the tools used on the slotter are similar to those used on the planer and the shaper and are clamped at right angles to the line of motion of the ram. Another class includes the tools that are set in line with the direction of motion of the ram and have the cutting edges formed on the ends of the shanks. A roughing slotter tool is shown in Fig. 27 (*a*). The shank is square, and the end is formed much like a parting tool; however, the cutting is done by moving the tool downwards, in the direction *DC*, and the chip is turned by the under face *E F*. The cutting edge is at the point *O*, and the clearance is the

angle between $D\,C$ and $K\,H$. The angle of front rake is the angle between $A\,B$ and $E\,F$. A good roughing tool for flat work is shown in (b); the blade of this tool is forged diagonally on the end of the shank. Roughing tools for slotter work have narrow points and finishing tools have wide points. If keyways and slots are to be cut on the slotter, the tool shown in Fig. 28 is used, the cutting being done by the edge $A\,B$ when the tool moves downwards endwise. This tool is apt to spring, and time and care must be used in making the cut.

FIG. 28

44. Slotter Bars With Fixed Tools. A large amount of steel is required for ordinary forged slotter tools; they are heavy to handle, hard to keep in good condition, and a large amount of space is required for storing them. To permit the use of small steel tools in the slotter, various forms of slotter bars have been devised, one of the most common forms of which is shown in Fig. 29. This consists of a rectangular body a, through which the bolt b is fitted. The bolt is held in position by a nut and a washer at c, and the lower end is slotted to receive the tool d, which rests against the head of the bolt e. The bar a is clamped to an ordinary slotter head by the regular clamps f and g, and the bolt b can be revolved in such a way that the tool d extends from the bar at any desired angle. This device facilitates the use of ordinary small planer or shaper tools in the slotter. The bar a can be adjusted up or down under the clamps f and g to some extent.

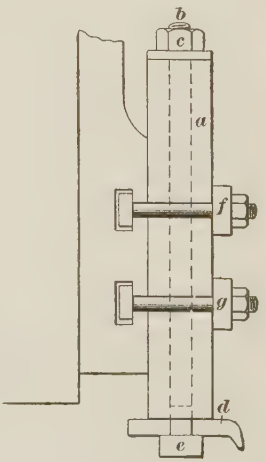


FIG. 29

45. Although the bar shown in Fig. 29 is fairly rigid for short work, it is not practicable if made long, and hence bars of the form shown in Fig. 30 are frequently used. In this case the regular clamps have been removed from the slotter head and two special clamps *B* substituted for them. These are held against the head of the ram by the bolts *b*. The slotter bar *c* passes through holes in the clamps and is held in position by the bolts *a*. A small steel tool is fitted in a slot in the lower end of the bar *c* and secured by a set-screw, as shown. The cylindrical form of the bar *c* allows it to be rotated so as to bring the tool or cutter to any desired angle of the work, but this will be found disadvantageous when slotting out irregular forms having internal angles, such as square holes.

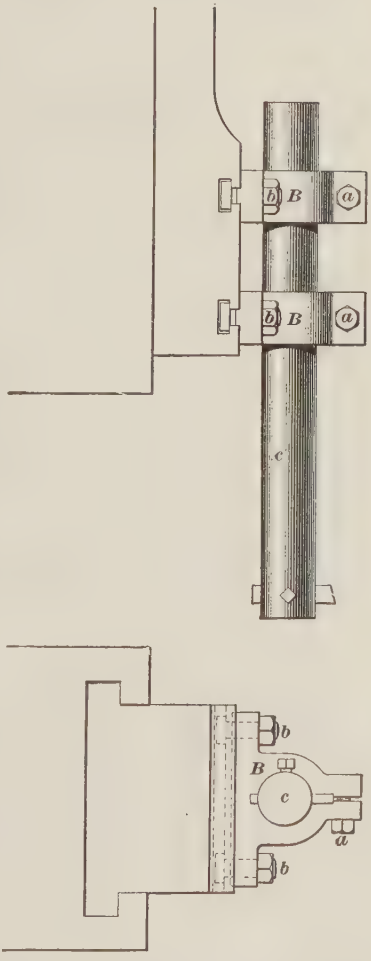


FIG. 30

46. The cutter blades or tools are rigidly fixed in both of the forms of bars shown in Figs. 29 and 30, and hence, on the return stroke, the tool drags over the work. If the tool is sharp, it will usually cut true enough so that the bar will be sprung very little on the return stroke, and the dragging of the tool will not injure the edge of the tool materially. If, however, too much top rake is given to the tool, the edge may break or crumble off on

the return stroke. The feeding of the work does not occur until the tool has returned to the top of the stroke, and hence the edge cannot be injured during the operation of feeding.

47. Slotter Bars With Tool Blocks.—Heavy slotter bars are made with tool blocks in the lower end that are pivoted in the same way that the tool block on the head of a shaper or planer is pivoted, so that on the return stroke the tool will lift away and not drag on the surface of the work. In such a bar the weight of the tool would naturally cause the block to hang away from the work at all times, and hence it is necessary to provide springs for holding the block against its seat. Sometimes the slotter tools themselves are drilled and fitted on pins and held in place by springs, so that the tool itself becomes a swinging block. Care must be taken with bars of this class to see that the springs always hold the block or the tool against its seat, and to prevent dirt from accumulating under the tool or the block; for if the tool is not firmly seated when the cut begins, it will come down against its seat suddenly and is liable to gouge into the work.

48. Stacking Work.—Frequently a number of pieces of the same class are to be finished at once. If these pieces are thin, much time may be saved by stacking or piling up a number of them and clamping all to the table so that the cut may extend across the entire pile. Fig. 31 illustrates this class of work. The two engine links *a* and *b* are placed one upon the other and clamped to the slotter table, parallel strips being placed under the work, as shown at *c*, and the tool is set so as to cut both pieces at one time. The parallels must be placed so that the work is supported

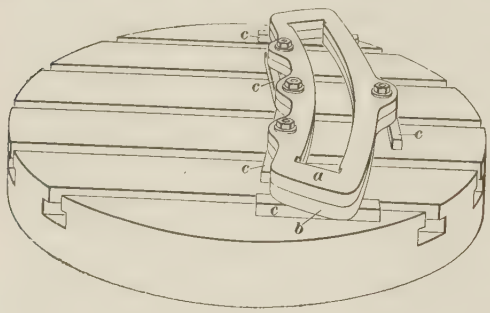


FIG. 31

close to the clamps, thus reducing the tendency to spring. In the illustration, five parallel strips are used and the work is secured by bolts through the regular bolt holes of the piece. Frequently the work is secured by means of blocks and clamps. It is possible to pile up as many pieces as the stroke of the machine can accommodate.

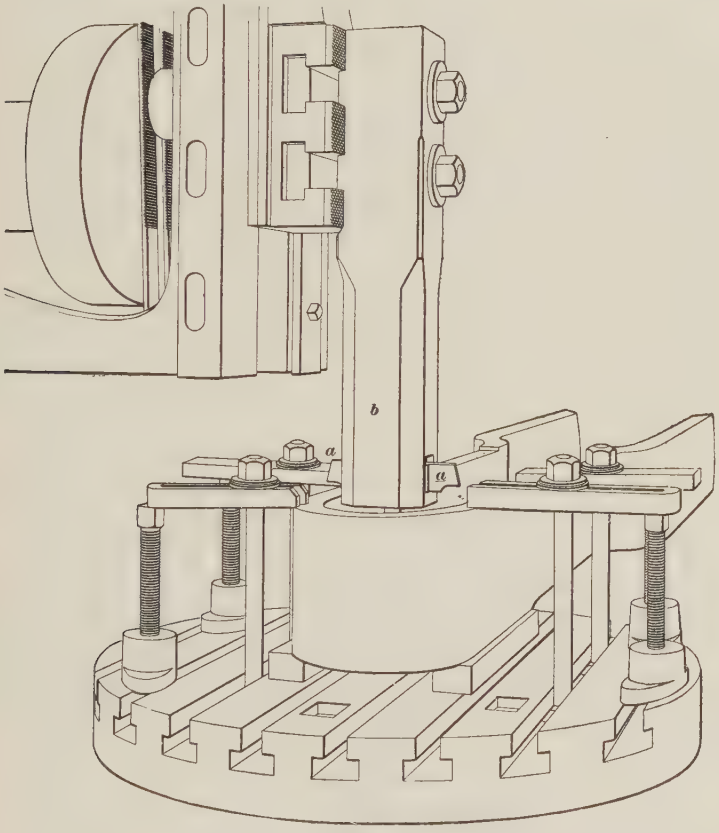


FIG. 32

49. Use of Double-Ended Cutter.—In Fig. 32 is shown a piece of work clamped to the table and ready for the cut. The work is a **U**-shaped forging that is to be finished on its inside surfaces. The curved part of the piece has been bored

to a diameter equal to the width between the surfaces when finished. A very heavy slotter bar *b* is used with a blade *a* of the proper length; this projects at each side, and has cutting points at each end. When set so that it will just pass through the bored part, it is correctly set to take the finishing cut, which it does by cutting both surfaces at the same time.

50. Gear Cutting on Slotter.—The slotting machine is often used for cutting internal gears or for cutting very large spur gears. Fig. 33 shows part of a slotter and part of a large internal gear *a* that it is cutting. The work rests on a plate *c* that has been accurately notched on its edge with as many equally spaced notches as there are teeth to be cut in the gear. The plate *c*, which thus forms an index plate, is fastened to the gear and is mounted on the table of the slotter. Clamps *d* are fastened to the table for clamping the index plate and for carrying the stop-pin that holds the index plate in place. A stop *e* with check-nuts on either side is used to regulate the depth of each tooth. The cutter or tool *f* used for this gear is shaped to the correct outline of the teeth, and is carried in a special block fastened to the end of the ram. A similar tool block is shown at *g* and a tool at *h*, removed from the head. As soon as one tooth space is cut, the stop-pin in the clamp *d* is pulled from the index plate and the gear is revolved until the stop-pin will slip into the next notch of the index plate. After being clamped, a second notch is cut in the gear, and so on until all the teeth are finished. Very large gears may be cut in this way when supported properly on bearings away from the table, so that the edge of the gear rests on the table and is free to slide on its outer support an amount equal to the depth of the tooth.

KEYWAY CUTTERS

51. Construction of Keyway Cutter.—The keyway cutter, or *keyseater*, one form of which is shown in Fig. 34, consists of a cutter bar *a* moved up and down from beneath by a ram driven by gearing, in a manner similar to that in which a geared shaper is driven. A table *b* supports the work, which in

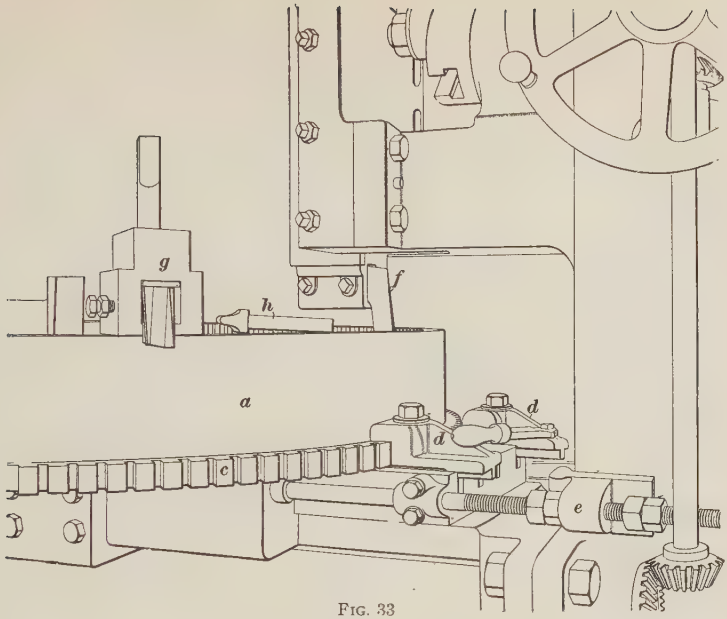


FIG. 33

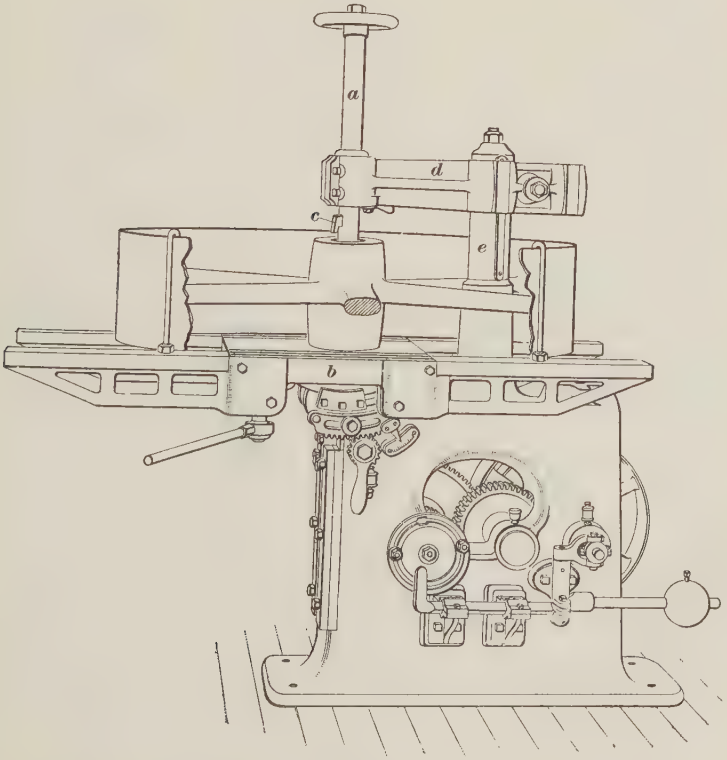


FIG. 34

large machines is fed automatically against the cutter *c* in the bar, and in small machines is fed by hand. The overhanging arm *d*, which is adjustable on the column *e*, gives support to the upper end of the cutter bar. The gearing for the driving and the feed is in the base of the column and the reversing mechanism is on the side shown in the illustration.

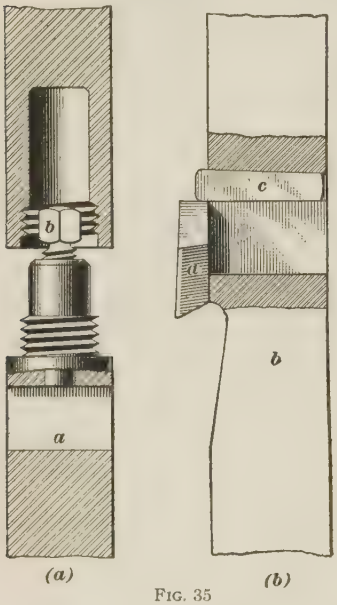


FIG. 35

52. Cutter Bars.—Small cutter bars are usually made in two parts that may be screwed together. Fig. 35 (*a*) shows the parts unscrewed, and also shows the method of clamping the cutter in the bar. The cutter passes through the slot *a* and is clamped by the setscrew *b*. These bars are made in various sizes to accommodate different sizes of work. Large cutter bars are made solid, as shown in (*b*), the cutter *a* being inserted in a slot in the bar *b* and held by driving in the key *c*.

53. Cutters for Keyways. A form of cutter for cutting a keyway is shown in Fig. 36. The shank *S* fits the cutter bar, and the part *C* does the cutting, the cutting edge being along the line *A B*. Cutter blades of this kind are accurately made of different widths for cutting keyways of standard sizes. All the grinding done is on the bottom face when they are resharpened. If the keyway is too small, so that a regular cutter cannot be used, the saw cutter shown in Fig. 37 may be employed. It consists of a bar *a* having a

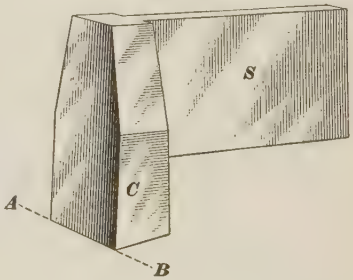


FIG. 36

number of cutting teeth along one edge. This bar is attached to the ram and an up-and-down motion like that of the cutter bar is given to it.

54. Duplicating Work on Keyway Cutter.—If there are a large number of turned pieces to be machined exactly

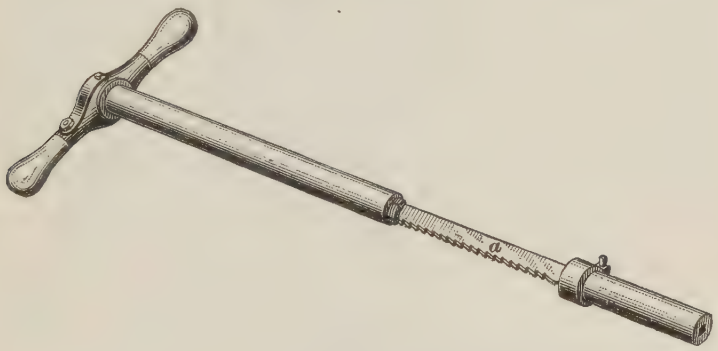


FIG. 37

alike on the keyway cutter, much time may be saved by using a holding fixture. For example, in Fig. 38 is shown a **V**-shaped holding fixture *a* that is intended to be clamped to the table to hold a series of circular pieces, one of which is shown at *b*. Each piece in succession is brought into proper position for the cutting operation by simply pushing it snugly into the angle of the fixture and clamping it there.

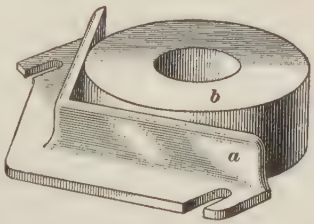


FIG. 38

55. Chucking by the Bore. The best method of holding a piece of work that is to be keyseated is shown in Fig. 39. This method is known as *chucking by the bore*. To the table *a* is bolted a flat plate *b*, the center of which is counterbored to receive the flange *c* of a bushing *d* that will fit accurately in the bore of the work. One side of the bushing is cut away to the full width of the central hole, making a space for the cutter *e* and allowing the work to be fed up to the cutter so as to give the required depth of cut. Bushings of

different sizes are required if the bore of the work varies. The advantage of chucking by the bore is that the work is held true, whether its hub is faced or not.

56. Cutting Keys on Keyway Cutter.—The keyway cutter may also be used for planing keys, by the application of the fixture shown at *a*, Fig. 40. This fixture is a vertical vise that is bolted to the table *b*. On the vertical face the vise carries two adjustable jaws between which the stock for the key *c* is gripped. The jaws are tightened by the screws *d* at the side. The cutter *e* is then set and cuts are taken just as in planing keyways. The cutter takes a full-width chip at each stroke.

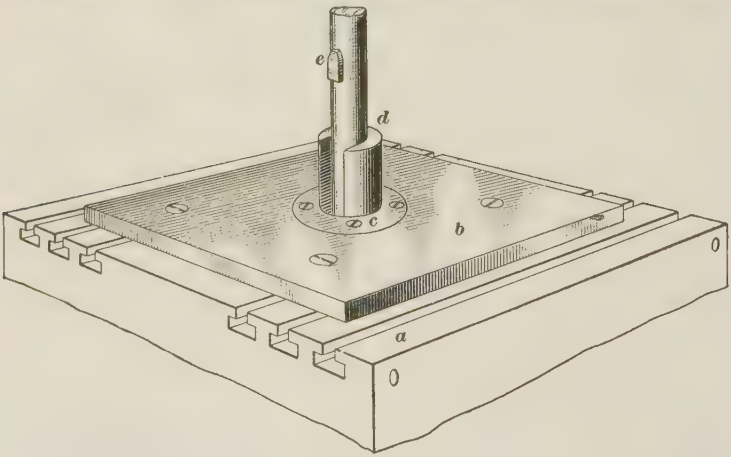


FIG. 39

57. Cutting Racks on Keyway Cutter.—Although the keyway cutter is designed particularly for certain classes of work, it is possible to do a number of other classes of work on it. A method of fitting up the machine for cutting racks is illustrated in Fig. 41. A cutter blade that will produce the desired tooth form is used and the rack is clamped to the table, as shown. The graduated feed-screw *a* is used to space the teeth and the cross-feed screw *b* to set the work for the proper depth of tooth. By the use of specially formed cutters and some special attachments, many kinds of slotter and shaper work can be done on the keyway cutter.

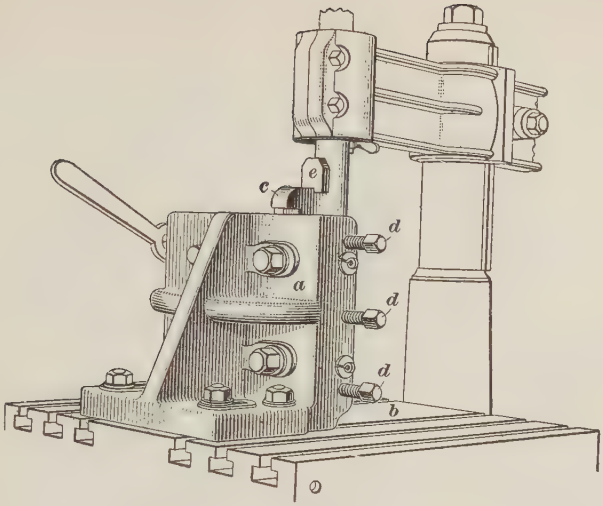


FIG. 40

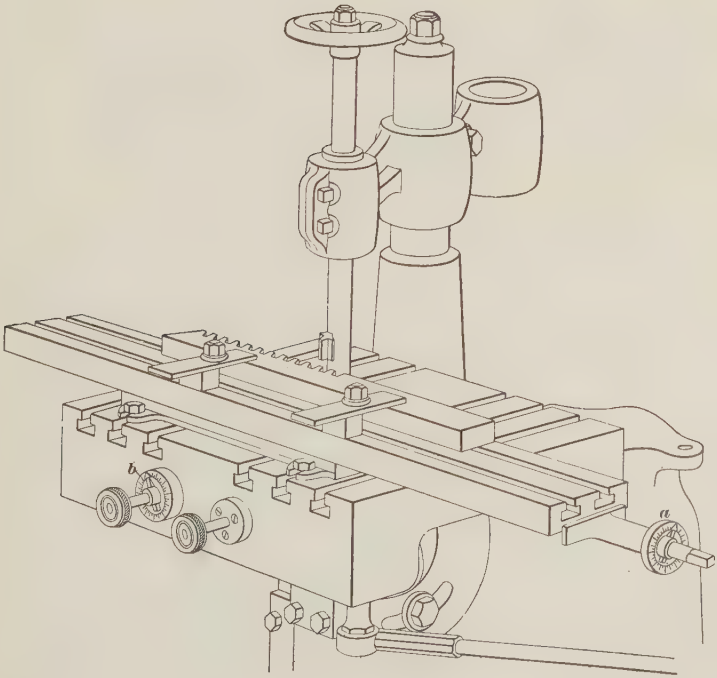


FIG. 41

MACHINE BROACHING

58. Broaching Machine.—The operation known as **broaching** consists in shaping or finishing a hole in a machine part by pulling a suitably formed broach or cutter bar one or more times through the hole, which has previously been drilled, reamed, or cored in the work. A machine for doing this class of work is shown in perspective in Fig. 42 and in section in Fig. 43, corresponding parts in both illustrations being marked by the same reference letters. It consists of a heavy base *a* carrying the main driving shaft *b*, on which are the double tight pulley *c* and the corresponding loose pulleys *d* and *e*. On the shaft *b* is a double pinion *f* that may be moved along the shaft by the hand wheel *g* so as to mesh with the gear *h* or the gear *i*. The

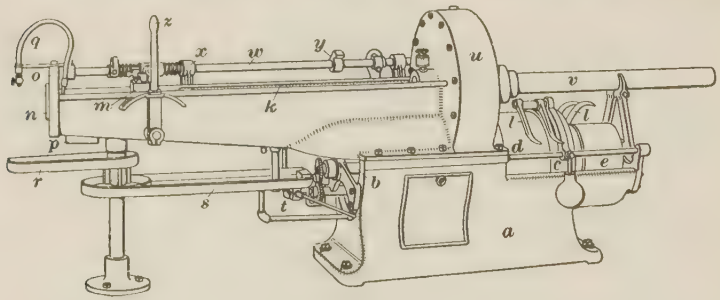


FIG. 42

gears *h* and *i* are fixed to the long nut *j* through which passes the screw *k*, and when the nut is turned by one of the gears, the screw is moved endwise, without turning. The double pinion enables the screw to be moved slowly for heavy broaching or rapidly for lighter work, and the double pulley *c*, in connection with the belt shifters *l*, allows the screw to be returned rapidly for the next operation.

59. The end of the screw *k*, Figs. 42 and 43, carries the sliding head *m*, which keeps the screw from turning and to which the broach is attached. The broach extends through the bushing *n*, which is fitted in the end *o* of an extension of the main frame. As the screw moves inwards, drawing the broach or

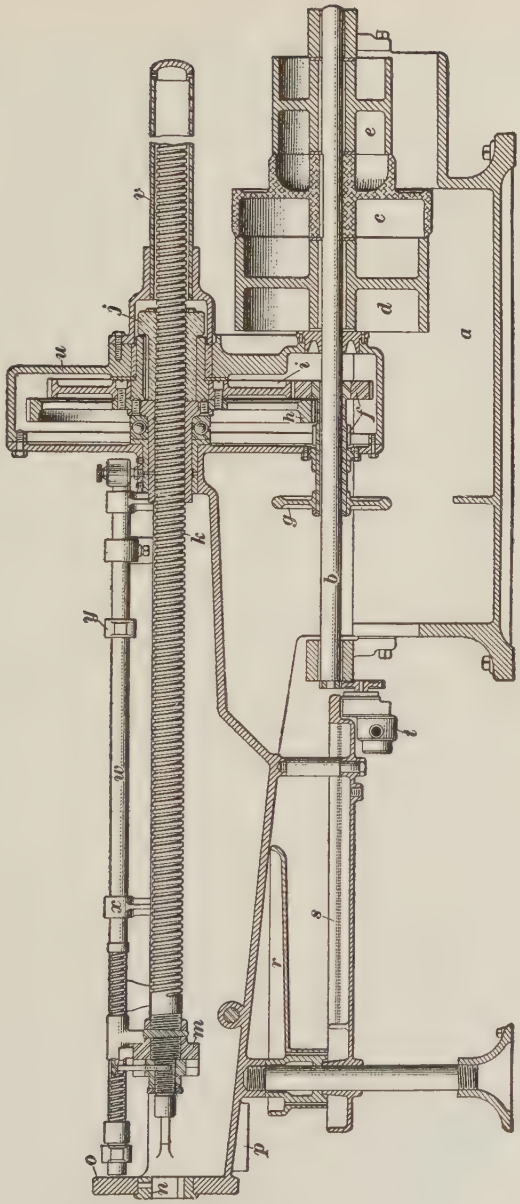


FIG. 43

the cutter bar with it, the work is forced against the end *o* by the pressure of the cut, and is thus held. A lug *p* is formed on the under side of the frame; to this may be fastened a table or some other form of support for the work. During the broaching operation, lubricant may be supplied through the pipe *q*. It then drips into the tray *r*, which may be swung underneath the frame when not required, as shown in the sectional view. From the tray *r* it runs into the tray *s* and thence into a settling chamber in the bed *a*, from which it is drawn by a geared pump *t* and returned to the work. The casing *u* protects the gearing, and the casing *v* keeps dirt and dust from settling on the end of the screw. The rod *w* carries tappets *x* and *y* that limit the length of the stroke and is connected with the belt shifters *l*, so that the motion of the screw is reversed automatically; also, the machine may be started or reversed by moving the handle *z*.

60. Broaching Tools and Attachments.—A broaching tool for cutting four grooves at once is shown in Fig. 44. There are four rows of cutting teeth *a* formed on a long bar *b*, and the size gradually increases from the point *c* to the end *d*. A slot is cut at *e* to receive

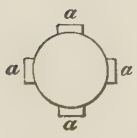


Fig. 44

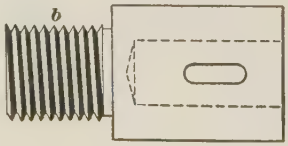


Fig. 45

Fig. 46

the key by which the tool is held to the pull bushing shown in Fig. 45. The pull bushing has a socket *a* to receive the end of the broach and a threaded end *b* to be connected to the pulling screw *k*, Fig. 43. It thus forms a means of fastening the broach to the pulling screw. A cutter bar for broaching a single keyway is shown in Fig. 46. The cutting teeth are formed on one

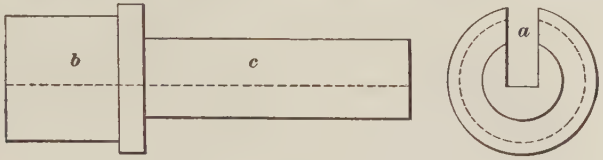


FIG. 47

edge of the bar *a* and the end *b* is threaded to fit the machine. The tool is guided by the arbor, or bushing, shown in Fig. 47, in the slot *a* of which it slides. The part *b* fits the machine and the part *c* the bore of the work.

61. Preparing Work for Broaching.—Castings that are to be broached without being otherwise machined should be well cleaned, so as to remove the sand from the surfaces; also, it is well to pickle them, so as to remove the scale and thus prevent the broaching tools from being dulled quickly. In most cases in which broaching is to be done, the holes are first drilled, bored, or reamed nearly to the finished size in order to reduce the amount of material that the broach must remove. One or both ends of the work should be squared, so that it will rest flat against the machine face and thus insure a broached hole square with the faces. If an arbor is used, the work does not need to be faced, as the arbor centers it and insures true work.

62. Broaching Operations.—Several different forms of cuts that may be made by broaches of suitable shape are shown in Fig. 48 (*a*) to (*h*). If a single straight groove is to be cut, as in (*b*), an arbor like that shown in Fig. 47 is put on the machine, the work is slipped on it, and the cutter bar is pushed through it and secured to the adjustable head on the pulling screw of the machine. The machine is then started, and as the cutter moves, the first tooth takes a light cut, and each succeeding tooth, being

longer, deepens the cut. When the cutter bar has been pulled through, the cut will be of the required depth.

63. If two keyways are to be cut directly opposite each other, as shown in Fig. 48 (*c*), the arrangement shown in Fig. 49 may be used to advantage. An index plate *a* is firmly fixed to the arbor *b*, which is set into the machine so that it cannot rotate. The work *c* in which the keyways are to be cut is clamped in a dog *d* and slipped over the arbor *b*. The slot *e* in the dog fits over a pin *f* in the index plate, and this pin is one of four that are equally spaced on the plate. With the work in this position the cutter bar is inserted and one keyway is cut.

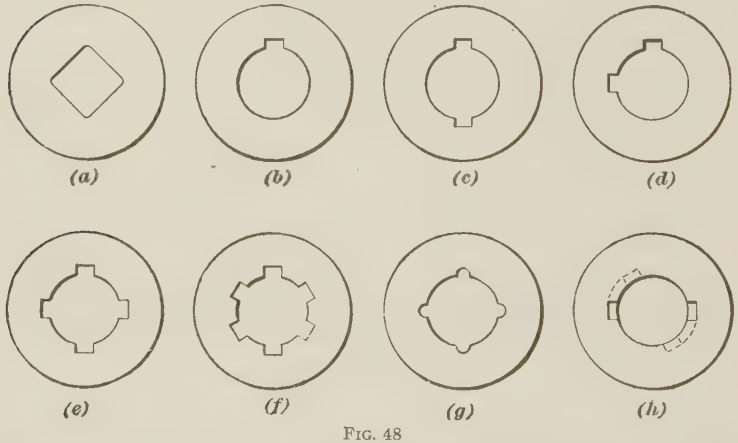


FIG. 48

The work is then slipped along the arbor *b* so as to release the dog from the pin *f*, and the work and the dog are turned until the slot can be slipped over the pin *g* directly opposite, after which the second keyway is cut. Any number of grooves may be cut in this way by using an index plate with pins properly set; but if several grooves are to be cut, the work may be done more quickly by using a formed broach that will cut all at one time.

64. A spiral groove, as shown in the end view, Fig. 48 (*h*), may be cut with a broach. The cutting teeth on the broach are arranged in a spiral exactly like that to be cut. The work is set with a ball bearing behind it, to allow it to turn easily,

and the broach is drawn through it. The teeth that cut first on the spiral broach should be longer than on a straight broach, so as to give the cut a good start.

If the parts to be broached are short, several of them may be placed end to end on the arbor and cut at one operation. Slots of extra depth may be cut by slipping a key behind the cutter bar in the slot made by the first cut, and then taking a second cut. In this, as in all other broaching operations, at least two teeth of the broach should always be in contact with the work, so as to steady the cut. As the broach is pulled, instead of being pushed, there is little tendency for the tool to chatter. The usual cutting speed of the horizontal broaching machine is from 3 to 6 feet per minute.

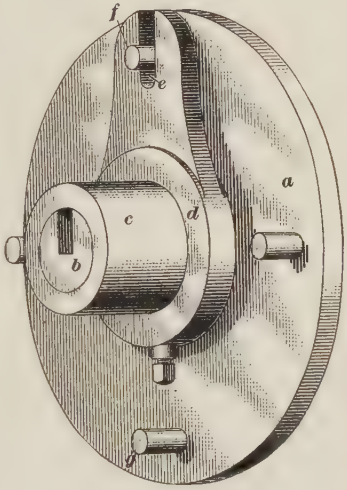


FIG. 49

65. Number of Broaches Required.—A single broach may be used to cut a hole in cast iron, if the hole is not too long; but if the hole is of considerable size and length and the metal is steel or wrought iron, it may be necessary to use as many as five broaches in succession, to complete the hole, each removing about the same amount of metal. The kind of metal, the length of the cut, and the amount of cutting to be done to bring the hole to the desired shape are the points that determine how many broaches are needed.

66. Lubricants for Broaching.—The lubricants that will give the best results when high-speed steels and other hard materials are being broached are lard oil and other cutting oils. For ordinary soft steels and steel castings, a cheaper lubricant may be made by mixing $2\frac{1}{2}$ pounds of salsoda, 3 gallons of mineral lard oil, and 10 gallons of water, and then adding 40 gallons of water. Cast iron and bronze are usually broached dry.

MILLING-MACHINE WORK
(PART 1)

MILLING MACHINES AND CUTTERS

TYPES AND CONSTRUCTION OF MACHINES

DEFINITIONS AND CLASSIFICATION

1. **Milling** is the process of removing metal by a cutting tool that is rotated about its own axis and usually has several cutting edges that one after another are brought into action on the work. Any machine in which this process is performed is called a **milling machine.** A great variety of milling machines are made to suit different conditions and requirements. According to their design and the class of work for which they are intended they may be called *plain*, *vertical*, *universal*, *multispindle*, and *special*.

2. **Kinds of Milling Operations.**—The various kinds of work done on the milling machine may be classed as *plain milling*, *side milling*, *face milling*, *angular milling*, *grooving*, *form milling*, *profiling*, and *routing*. The first three operations named are performed on, and result in the production of, plane or flat surfaces. Curved or irregular surfaces are produced by the last three operations.

3. **Plain milling** is a milling operation on a flat surface that is parallel to the axis of rotation of the cutting tool. If the tool and the spindle are true, as they should be, this axis is the center line of the spindle. **Side milling** is performed on a flat

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surface that is at right angles to the axis of rotation of the cutting tool. **Face milling** is the production of a flat surface at right angles to the table of a horizontal milling machine by the use of a face cutter. **Angular milling** refers to the milling of flat surfaces that are at an angle to the axis of rotation of the cutting tool. **Grooving** consists in cutting grooves or slots that may be straight, helical, or irregular.

4. Form milling is milling done on surfaces that are not flat, but that have the same outline throughout, in the direction in which the work is fed against the cutting tool. In **profiling** the work is guided by the use of a templet of the required form, thus producing work of the desired shape. **Routing** refers to a milling operation in which the work is fed to the cutting tool and guided by hand, the result depending wholly on the skill of the operator.

5. Kinds of Milling Machines.—The **plain milling machine** is intended only for finishing surfaces that require the motion of the work to be limited to a straight line at right angles to the axis of the cutter. The work table is gibbed in the slides and must travel square with the spindle; it cannot be swung on a pivot horizontally as is the case with the table of the universal machine. It is so arranged that the work can be fed to the cutting tool in a vertical direction, and also in two horizontal directions at right angles to each other. The axis of rotation of the cutting tool is usually horizontal. As the greater part of general milling is plain milling, plain machines are extensively used.

6. The **vertical milling machine** derives its name from the fact that the axis of rotation of the cutting tool is vertical. It is usually so arranged that the cutting tool can be fed toward or away from the work in a vertical direction, while the work can be fed to the cutting tool vertically and in two horizontal directions at right angles to each other. In some cases the machine is so arranged that the work can be revolved in a horizontal plane for the purpose of finishing circular surfaces.

7. The **universal milling machine** differs from the plain milling machine in that the angle of the table with the spindle may be changed, and the machine is arranged to receive numerous attachments that render it available for use in a wider range of milling operations. The axis of rotation of the cutting tool is usually horizontal; the work can be fed to the cutting tool in a vertical direction, and also in two horizontal directions. By means of change gearing the work can be rotated at the same time that it is moved in a horizontal direction, and the machine is thus adapted for the production of spiral work. The work can also be rotated in these machines through any definite part of a turn for each individual cutting operation.

The special devices fitted to a universal milling machine may also be applied to a plain or a vertical milling machine, which are thus to some extent converted into universal milling machines. They will rarely have as wide a range of application, however, as a machine especially designed to be a universal milling machine.

8. The **multispindle milling machine,** as implied by the name, is fitted with two or more spindles that carry the cutting tools. Each spindle, and hence each cutting tool, is usually made to be independently adjustable in relation to the work. In most machines of this class, the work can be moved in a straight line in one direction only. Multispindle milling machines are intended for finishing several surfaces simultaneously, and are usually employed for heavy work.

9. **Special milling machines** may take any conceivable form that will adapt them for the class of work for which they are designed; but no matter how they are constructed, the principles of operation will be the same as those of any regular milling machine.

CONSTRUCTION OF MILLING MACHINE

10. **Main Parts.**—A milling machine consists of certain main parts, which in some form must exist in every machine of this kind. The necessary parts are the frame, the spindle, the table, the feed-mechanism, and the cutting tool. The use

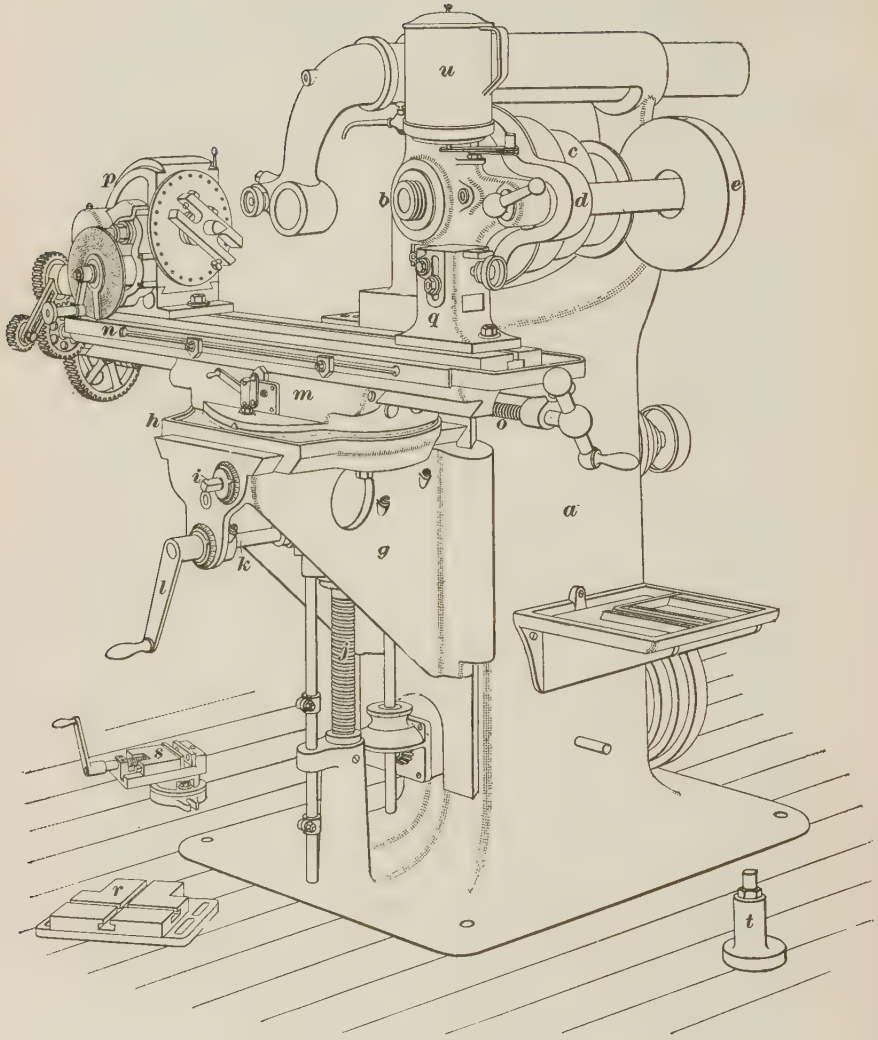


FIG. 1

of the frame is to support the spindle, table, and feed-mechanism. The spindle is revolved by belt or gearing in bearings provided for it in the frame and carries the cutting tool. The table serves as a support for the work, which may be attached either directly to it or to holding devices carried by it. The feed-mechanism moves the work past the cutting tool and may operate directly on the table, on a head carrying the spindle, or on both.

11. Construction of Universal Milling Machine. The universal milling machine is the most advanced form for general work, and includes all the features found in other types. For this reason it is here selected and described. As far as the universal machines of various makes are concerned, their general arrangement resembles that of the machine illustrated in Fig. 1; they differ only in the design of the details.

12. The general form of the frame *a*, Fig. 1, is that of a column, or pillar, and hence this is known as a *column-type*, or *pillar-type*, *milling machine*. The frame carries the horizontal spindle *b* near its top. The spindle is driven by a belt from a countershaft to the cone pulley *c*. The countershaft is driven from the main shaft or the line shaft by a crossed and an open belt running on loose pulleys with the tight or driving pulley between them. When both belts are on the loose pulleys, the spindle stands still; but it is revolved to the right or to the left by shifting the open or the crossed belt to the tight pulley. Machines with constant-speed drive, however, are driven by a single belt and are reversed by reversing gears in the driving train.

13. The machine shown in Fig. 1 is back-geared to enable it to take heavier cuts and to give a larger number of speed changes. The back gearing is similar to that employed for engine lathes and is operated by a handle. The back gears are protected by light metal guards shown at *d* and *e*. The spindle is bored tapering at the front end to receive the shank of the cutting tool or an arbor to which the cutting tool is attached. An adjustable arm, or an outboard bearing sliding in bearings

parallel to the spindle, can be used to support the free end of the arbor when heavy cuts are taken, and when not in use it can be swung out of the way. The arm can be clamped rigidly in position after it has been adjusted.

14. A vertical slide is formed on the front of the frame *a*, Fig. 1, and a knee *g* is fitted to this slide, which is in a plane at right angles to the axis of the spindle. The top of the knee is at right angles to the surface of the slide on the frame, and carries the clamp bed *h*, which can be moved along it in a straight line parallel to the axis of the spindle by means of the cross-feed screw *i*. The knee can be raised and lowered by turning the elevating screw *j*; for convenience, this is operated from the front of the knee by turning the shaft *k*, which carries a bevel gear that meshes with one on the elevating screw. A detachable handle *l* fits the square ends of *i* and *k*. The cross-feed screws and elevating screws are supplied with dials graduated to indicate movements by thousandths of an inch.

15. The clamp bed *h*, Fig. 1, carries the saddle *m*, which is pivoted to it and can be rotated through an angle of about 45°. Suitable clamping devices are provided to clamp the saddle to the clamp bed in any position to which it may be swung. The upper part of the saddle forms a slide that receives the table *n*, which slides in a line parallel to the top surface of the knee. The table can be moved by means of the feed-screw *o*, which is operated by the handle shown. The top of the clamp bed is graduated in degrees. When the zero mark on the saddle is in line with the zero line of the graduation, the line of motion of the table is *at right angles* to the axis of the sipndle; and when it is in line with some other graduation, it shows how many degrees the line of motion differs from its position at right angles to the axis of the spindle.

16. The table is fitted with a detachable index head *p*, Fig. 1, and a detachable tailstock *q*. The index head and the tailstock are fitted with centers between which work may be held. The spindle of the index head may be rotated by means of a worm-wheel and worm, and it is so arranged that it may

be swung in a vertical plane around the axis of the worm from slightly below a horizontal position to somewhat beyond a vertical position. On the bottoms of the index head and the tailstock are tongues that fit the central lengthwise T slot in the table, thus insuring that the axis of the index-head spindle is in line with the tailstock spindle. The front end of the index-head spindle is threaded to receive face plates, chucks, or special devices for holding work. The spindle is made hollow and is bored tapering to receive a live center or arbors.

17. When it is necessary to set the spindle in the index head at an angle to the line of motion of the table, owing to the form of the work secured in the index head, the head is detached from the table. A raising block *r*, Fig. 1, is bolted to the table in such a position that one of its two T slots is at the required angle, and the index head is bolted in that T slot of the raising block. When the diameter of the work is so large that it cannot be swung by the index head if the latter is fastened directly to the table, special raising blocks are used under the head and the tailstock. When no raising blocks are available, parallel strips may be used. The tailstock *q* has the dead center mounted in a block fitted to a slot of the tailstock. This block can be raised or lowered a certain amount to bring the dead center in line with the live center when tapering work is held between them.

18. A **milling-machine vise** *s*, Fig. 1, that can be swiveled and then clamped in any position to the table, is used for holding work. When comparatively slender work is to be milled between the centers, it will naturally spring under the cutting operation. This tendency is counteracted by placing a center rest, or steady rest, *t* on the table and adjusting it properly to support the work. An oil tank is shown at *u*.

The machine is provided with an automatic feed for the table, which, by means of adjustable tappets, can be made to stop at any desired point. A vertical feed for the knee is also provided. The knee and the clamp bed may be clamped rigidly to their slides at any point by clamp screws. Adjustable

stops are also provided for the knee and the table. They are used when a number of duplicate pieces are to be milled, and the feeding is done by hand. The inside of the frame of the universal milling machine usually serves as a cupboard in which cutters, change gears, collets, arbors, wrenches, and other small parts may be kept conveniently.

19. The table of the universal milling machine will move endwise the amount of the backlash between the nut and the feed-screw, and it must be prevented from moving endwise while drilling and some other operations are being performed. The table is held in position by the table stop, shown in Fig. 2. This consists of a casting *a* slotted with square shoulders and held in position on the dovetail of the table by the loose gib *b*, which is secured to the body of the stop by a screw. The stop is clamped to the table at any desired point and any fine adjustment required is made by means of the screw *c*. The stop may be applied to the table on either side of the saddle and when the feed-screw is operated to force the table and the stop against the saddle, cuts either vertical or parallel to the spindle axis may be made safely.

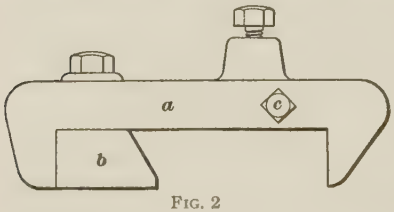


FIG. 2

20. In one form or another, milling machines of different types have some of the features of the universal milling machine. In one case the cutting tool may be fed to the work, and in another case the work may be fed to the cutting tool; the feeding may sometimes be accomplished by a lever operating on a pinion and rack, and at other times the feeding may be done by turning a feedscrew; no matter, however, in what form the necessary parts appear and what their construction may be, it will be found that their fundamental principles and their use are the same in each case.

Furthermore, a person that can operate one type of machine successfully can, after getting accustomed to the methods of adjustment of another type, operate it with equal ease. The

special methods of adjustment can be readily traced out. For this reason, no attempt is here made to describe all the different types and the subclasses of each type in detail.

ADVANTAGES OF MILLING MACHINES

21. It was conceded for a long time that milling was superior to other processes of machining because, by the use of properly formed cutting tools, pieces of work having intricate profiles could be so nearly duplicated as to be interchangeable. This could be done at a rate impossible with any other method of machine work, and consequently at a lower cost per piece. The milling machine has made possible the application of the interchangeable system to the economic production of work done in large quantities, as firearms, sewing machines, typewriters, etc. It was developed originally in armories manufacturing small firearms, and for a long time was unknown elsewhere. It is now recognized that the process of milling can be applied to a great variety of work usually performed in the planer, shaper, slotter, and lathe, and that because of the large number of cutting edges and the continuous cutting operation, the work in many instances can be machined by milling at a much lower cost.

22. Although the operation of a milling machine calls for skill of a very high order, yet when machining duplicate work in large quantities one operator may sometimes run two machines to advantage. When this is the case, the operator first sets up the work on one machine and starts the cut, using the power feed. While the cut is being taken, the work is set up on the other machine and the cut started. As soon as the cut is finished on the first machine, the work is removed and another piece is set up and the cut started again. These operations are then repeated, the work being set up on one machine while the other is taking a cut.

23. When high-speed-steel cutters are used, the time required to make the cut is generally reduced to such an extent

that one man cannot operate two machines to advantage. It is usually better economy to use cutters that will stand high speeds and deep cuts and that will require the constant attention of the operator at the machine, than to have one man operate two machines that are fitted with cutters that take lighter cuts at slower speeds. All the conditions should be studied carefully before adopting a plan for doing the work.

MILLING CUTTERS

CLASSIFICATION

24. The cutting tool used for milling is known as a **milling cutter,** or simply as a *mill.* Milling cutters may be classified as *plain milling cutters,* also called *common, slab,* or *surface milling cutters; side milling cutters; face, butt,* and *end milling cutters; angular milling cutters, formed cutters,* and *form cutters.* Side

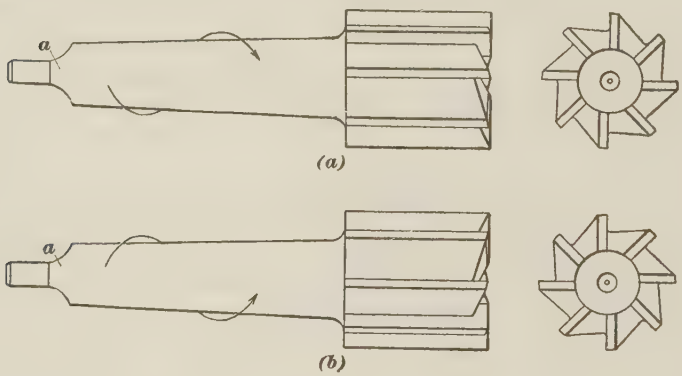


FIG. 3

mills and end mills are also called *radial mills.* Any one of these cutters may be a solid, an inserted-tooth, a shank, or a shell cutter, and it may be fastened to the spindle of the milling machine by holding it in a chuck, by clamping it on an arbor, by screwing it to the spindle or to a shank fitted to the latter, or, finally, it may be formed with a shank that fits the spindle.

25. Milling cutters are called right hand and left hand, according to their direction of rotation when cutting. To ascertain whether a cutter is right hand or left hand, lay it down flat with that side of the cutter up which is intended to face the driving cone of the machine. Then, if the cutter must revolve in the direction in which the hands of a watch move, in order to cut, it is a *right-hand cutter;* and if it must revolve in a direction opposite to that in which the hands of a watch move, it is a *left-hand cutter*. This way of stating the direction of the cutter comes from drilling. A drill that turns in the direction of the hands of a watch in order to cut, when looked at from the spindle end, is a right-hand drill, and the same rule has come to be applied to milling cutters. In Fig. 3 (*a*) and (*b*), for example, are two cutters, the first being right-hand and the second left-hand. In each, the tang end *a* is toward the driving cone of the machine. When viewed from this end, the cutter in (*a*) must turn in the direction of the hands of a watch, as shown by the arrow, and therefore it is a right-hand cutter. The one shown in (*b*) is a left-hand cutter, because it must turn in the opposite direction.

PLAIN MILLING CUTTERS

26. A **plain milling cutter** is one intended for machining surfaces parallel to its axis of rotation. The simplest form of plain milling cutter is the **slitting saw** shown in Fig. 4, which is clamped between washers on an arbor. A number of cutting edges are formed on its outer edge, and these cutting edges are ground after hardening until all are exactly the same distance from the axis, so that each will do the same amount of work. Slitting saws, like the one shown, are ground with clearance on the sides; that is, they are made slightly thinner at the center than at the outer edge, so that deep slots can be cut, or stock can be cut off, without having the sides of the cutter bind in the slot.

27. When shallow slots are to be cut, as, for instance, the slots in screw heads, the cutter is made with teeth set much closer together, and the sides are then usually left parallel, to

save expense in manufacture. This kind of cutter is given the name of screw-slotting cutter, as it is most frequently employed for that purpose. Although it is sometimes used for cutting off stock, it is not so well adapted for this purpose as the slitting cutter, as the sides of the cutter will bind when thick stock is being sawed, especially if the teeth are at all dull.

28. Parts of Cutter.—The term *pitch*, when applied to the teeth of a milling cutter, is the distance from one tooth to the next, measured on the outer edge, or circumference, of the cutter. As the teeth in milling cutters are equally spaced, the pitch can be found by dividing the circumference of the cutter by the number of teeth. The surface represented by the line *a b*, Fig. 4, is called the *front face* of the tooth. In American practice, it is almost invariably made radial; that is, the front face if continued passes through the axis of the cutter. In side milling cutters, this rule is occasionally departed from for the purpose of throwing the chips in a certain direction. The surface *a a'* is called the *land* of the tooth. The tooth angle included between the front face *a b* and the land *a a'* varies from 87° to 85°, thus giving a clearance of from 3° to 5°. The edge *a* is the cutting edge, and the surface whose edge is *a'c* is the back of the tooth. The cutter, in order to cut, must rotate so that the front faces of the teeth move *toward* the work, or in the direction of the arrow *x*. The pitch is indicated by *p*.

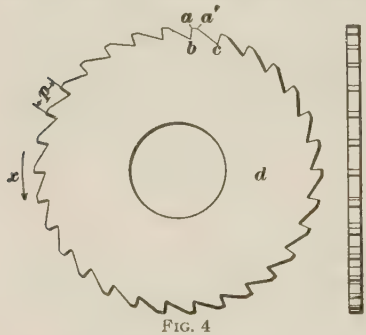
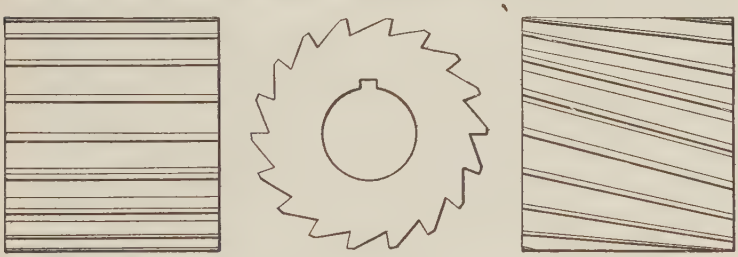


FIG. 4

29. Reversible Cutters.—Any milling cutter that can be placed with either side toward the spindle, as is the case with most plain milling cutters fastened on an arbor, is a reversible cutter. It will serve for either a right-hand cutter or a left-hand cutter, depending on which side of the cutter is placed toward the spindle. Thus, if the cutter illustrated in Fig. 4 is placed with the side *d* toward the spindle, it is a left-hand

cutter; but if the side *d* is placed away from the spindle, it is a right-hand cutter.

30. Straight Cutting Edges.—When the slitting saw is made wider, it becomes the plain cutter shown in Fig. 5 (*a*). Common practice limits the terms slitting saw and slotting cutter to cutters that are narrower than $\frac{1}{4}$ inch. When wider, they are usually called *plain cutters*, *cylindrical cutters*, or *parallel cutters*. The cutter shown in Fig. 5 (*a*) has straight cutting edges; that is, edges that are parallel with the axis. A milling cutter with straight cutting edges will answer very well for surfaces that are not more than about 1 inch wide, and it has the advantage that straight cutting edges are cheaply cut. On the other hand, each cutting edge, when in contact



(*a*) FIG. 5 (*b*)

with the work, will cut at once across the whole width of the surface operated on; consequently, considerable power will be needed, and as each cutting edge strikes throughout the whole width of the surface, a distinct blow is struck by it, which will set up vibrations and will go far to prevent smooth, even milling, unless the machine is exceptionally rigid and the work is held very securely.

31. Helical Cutting Edges.—The objections to the straight-tooth cutter have led to the design of the cutter with helical cutting edges, as shown in Fig. 5 (*b*). When a surface is being machined with this type, the teeth will commence cutting at one corner, and the cut will gradually proceed across the work. In consequence of this shaving action, the severity of the blow struck by each cutting edge on meeting the work is greatly

lessened. Experience has also shown that for the same conditions, less power will be required for a cutter with helical cutting edges than for one with straight cutting edges. The lessening of the severity of the blow struck by each edge on meeting the work means a reduction of vibration; consequently, under like conditions, the cutter with helical cutting edges will produce a smoother surface.

32. The power required to drive a helical milling cutter can be greatly reduced by *nicking the teeth* in the manner shown in Fig. 6, with a cutting edge behind each nick. The nicked cutter breaks the chips; that is, instead of one continuous shaving, a number of separate shavings are made by each cutting edge. As less power is required for a nicked cutter, it follows that with

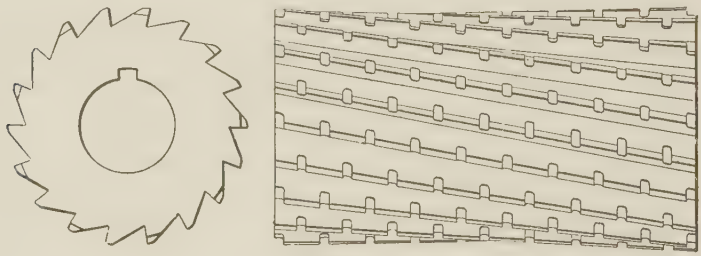


FIG. 6

the same amount of power available and under equal conditions, a much wider and deeper cut can be taken than is possible with an ordinary helical cutter. For this reason, cutters with nicked teeth are very generally employed for heavy milling where the rapid removal of metal is the main requirement. It is claimed that a surface cannot be machined as smooth with a nicked cutter as with a plain cutter; but if the nicks are given clearance and the cutter is kept sharp, there is no reason why it cannot produce as good work on a finishing cut as a plain cutter.

33. Built-Up Plain Cutters.—The cutters shown in Figs. 4 to 6 are solid cutters, which means that they are made from single pieces of steel. Solid cutters are made as large as 8 inches in diameter and 6 inches wide; but this size is about their commercial limit. When larger cutters are wanted, they

are usually made with blades or teeth of tool steel that are so inserted in a body of inexpensive material that they can be removed and replaced when worn or broken.

34. Built-up cutters may be made in a great many different ways. The construction adopted by the Morse Twist Drill and Machine Company for inserted-blade cutters is shown in Fig. 7 (*a*). The blades *a* are inserted in rectangular slots cut in the

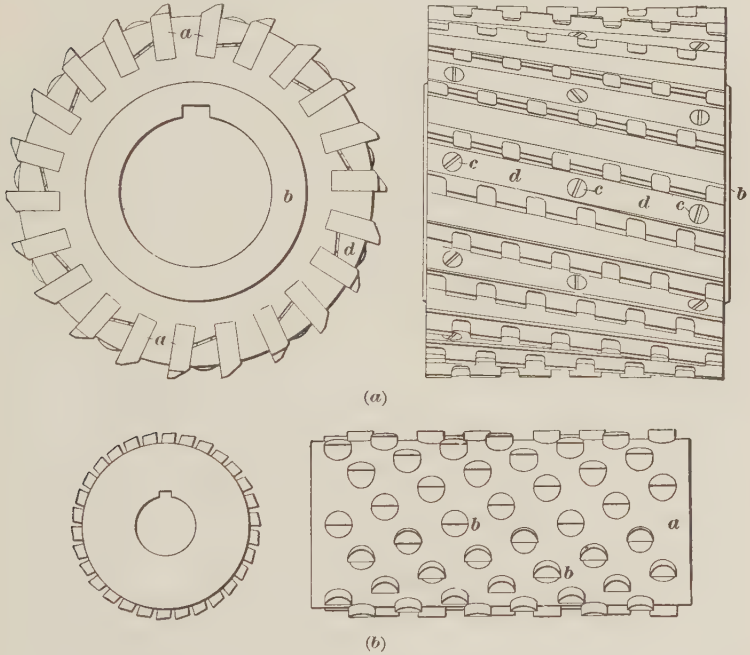


FIG. 7

body *b*. Between each alternate pair of blades is a clamp *d* that can be drawn inwards by tightening the screws *c*, which operation presses the two blades against opposite sides of their slots and locks them. The blades themselves are straight; but their cutting edges are helical, in order that the front faces of the blades may be radial throughout their length. The cutter here shown is intended for heavy work and consequently the cutting edges are nicked.

35. An entirely different design of plain or slab milling cutter is shown in Fig. 7 (*b*), which is of the inserted-tooth type. It is a development of the idea of nicking the teeth, inasmuch as each separate tooth is the equivalent of the cutting edge between a pair of nicks of an inserted-blade cutter or a solid cutter. The cast-iron or steel body *a* has rows of holes drilled and reamed to receive the teeth. The holes are so arranged that a tooth is always behind a space in the next row. The teeth *b* are round plugs of tool steel driven into the holes. A cutting edge is formed by cutting away the front half of that part of the plug that projects from the body, and grinding a proper clearance on its top. While the teeth are arranged in helixes around the body *a*, the cutting edge of each tooth is radial, thus preventing the teeth from turning around under the pressure of the cutting operation. If the front face of the tooth were slanted, or helical, it would commence to cut at one corner, and, consequently, there would be a tendency for the tooth to twist around.

36. Inserted-blade and inserted-tooth or built-up milling cutters are limited as to size only by the capacity of the machine. For large cutters, however, either the cost of the solid cutter is prohibitive, or it is impossible to obtain steel of sufficient size to make a solid cutter. Furthermore, in hardening very large pieces of tool steel, there is considerable danger of cracking them when quenching. Thus, the question of whether to use a solid or an inserted-tooth cutter is simply one of expense, as each will work as well as the other. When it comes to a question of maintenance, the built-up cutter is undoubtedly cheaper in the long run, as new blades or teeth can be fitted at a fraction of the expense of a solid cutter, at least so far as large cutters are concerned.

SIDE MILLING CUTTERS

37. Solid Side Mill.—The most common form of side milling cutter for small work is shown in Fig. 8. It is a plain milling cutter with additional teeth cut on its sides, and the sides below the bottoms of the teeth are recessed, as shown at *a*,

so they will clear the work. A side milling cutter may operate on the sides of work either by cutting with the cutting edges formed on its face or with the teeth formed on its sides, depending on which way the work is fed to the cutter. When the work is fed in a direction at right angles to the axis of rotation of the cutter, as is usual, the teeth on the face will do the cutting and the side teeth will drag alongside the work; but if the feeding is done in a direction parallel to the axis of rotation, the side teeth will do all the cutting.

38. Straddle Mills and Gang Mills.—Two side milling cutters like the one shown in Fig. 8 are often placed on an arbor, with a washer to regulate the distance between them. In this case two opposite sides of the work are operated on at one time and the combination is called a straddle mill. A gang mill consists of two or more cutters assembled together on the same arbor. It may be made up entirely of plain cutters or of a combination of plain, formed, and angular cutters. Gang mills are very useful for milling simple shapes, if plain cutters of the required diameter are available, as several surfaces may be operated on at the same time. For intricate shapes, special milling cutters are often made as gang mills.

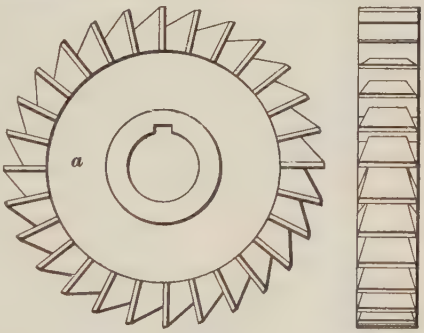


FIG. 8

39. Threaded Cutters.—When a milling cutter is screwed on an arbor, it should revolve in such a direction that the cutting operation will tend to force it against the shoulder on the arbor. It follows that any cutter threaded to an arbor cannot be run in *both* directions. If, for example, a plain side milling cutter is driven by a left-hand thread, this cutter must run left hand. If it is run right hand, the pressure of the cut will tend to unscrew the cutter. In case the cutter is unscrewed, the work may be spoiled by having the cutter dig into it, or the cutter may be

broken. Particular attention is called to this fact, as it is the cause of many of the accidents to the work and cutters.

40. Inserted-Blade Side Mills.—Small side milling cutters up to about 8 inches in diameter are usually made solid. Above that size cutters with inserted blades or inserted teeth are cheaper in first cost and maintenance. Inserted-blade side milling cutters may be constructed in a great variety of ways; for instance, they may be made with a clamp between every two cutters as shown in Fig. 7 (*a*), or the blades may be inserted and locked with taper pins, as shown in Fig. 9. The latter illustration gives the design adopted by the Pratt & Whit-

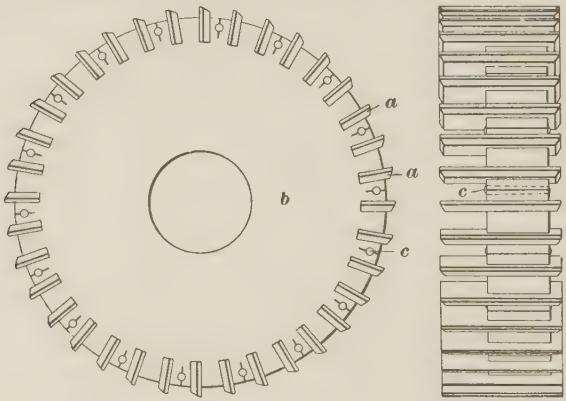


FIG. 9

ney Company. The blades *a* fit rectangular slots cut in the body *b*. A hole is drilled between every alternate pair of blades and these holes are reamed tapering, to receive the taper locking pins *c*. After reaming, slots are cut through the reamed holes and the blades are locked by driving the taper pins home. The blades are generally made long enough to allow them to be sharpened many times.

41. Face Milling Cutters.—For milling the sides, ends, or edges of work, or for making other facing cuts, face milling cutters, or *face mills*, as they are called, are utilized. The small sizes are sometimes made as solid cutters with shanks to fit the taper in the spindle. Larger face cutters are made as

solid steel cutters, which are driven or screwed on tapered arbors. Larger face cutters, made with inserted teeth, as shown in Fig. 10 (*a*), are either screwed on threaded arbors fitting the spindle taper or on suitably threaded spindles. Medium-sized and large face mills are made with cast-iron bodies and inserted teeth, as shown in (*b*). The front and back surfaces *a* of the body are beveled and holes are drilled square with one of these faces for the cutters *b*. The cutters are of round steel milled flat on the cutting face and at the point where the setscrews clamp them. The largest sizes of face mills are usually made with notches *c* in the outer edge and the setscrews *d* used for holding the cutters are placed in the notches.

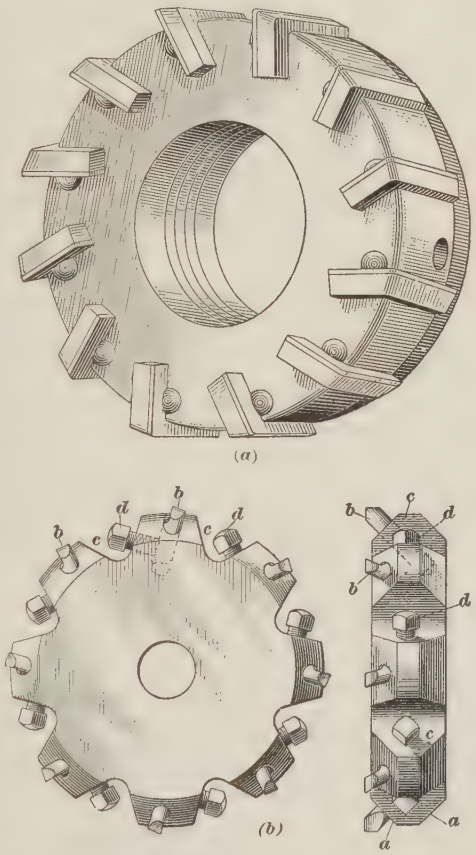


FIG. 10

42. A different form of face cutter is shown in Fig. 11. The teeth *a* are made of square tool steel and are placed in rectangular slots in the body *c*. The slots are parallel to the axis of the cutter, and the teeth are held by setscrews *e*. The particular cutter shown is fastened to the spindle *d* by a key *f*. Longitudinal movement on the spindle is prevented by a screw *g*, which is placed half in the shaft and half in the body. This

method of fastening a cutter to the spindle is adapted only to cases in which the cutter body is not intended to be replaced by others of different shape or size.

43. By using the design of cutter shown in Fig. 11, a surface may be roughed out and finished by running the cutter over it but once. Two or more flat-nosed tools *b* are placed in a circle that is slightly inside the circle of roughing teeth *a*. The cutting edges of these inner tools are adjusted to cut slightly deeper than the roughing teeth. Consequently, the roughing teeth *a*

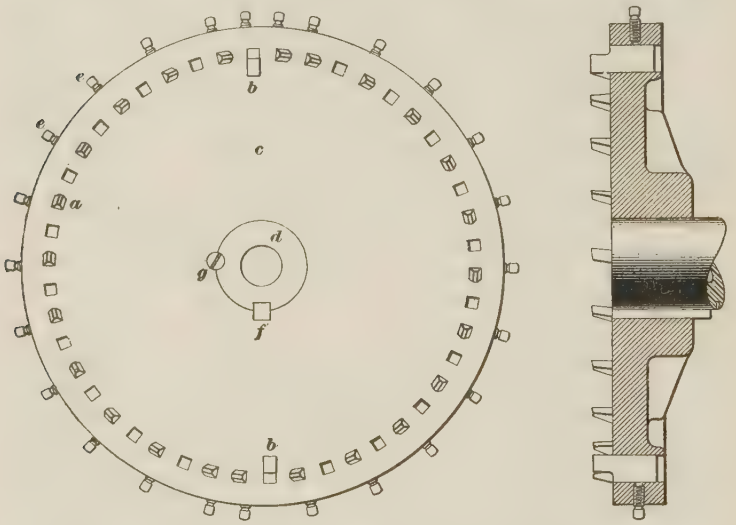


FIG. 11

will rough out the work in advance of the finishing tools *b*, and as the cutter moves past the work, the finishing tools follow directly behind the roughing teeth and take the finishing cut. This process greatly reduces the time required for the cutting operation. Cutters designed to take a roughing and a finishing cut at the same time are applicable only to work that is so rigid that there is no danger of its springing to an appreciable extent by the releasing of the tension existing at the surface of castings and forgings. Plain milling cutters cannot take a roughing and a finishing cut simultaneously.

44. T-Slot Cutter.—The cutter shown in Fig. 12 is a side milling cutter that is used to cut T slots and is designated as a T-slot cutter. It is made with a tapered shank *a* that fits the hole in the spindle or in a collet. Instead of having a tapered shank, however, the cutter may be threaded so as to screw on a shank or an arbor. The end of the shank is milled to form a tang that enters a corresponding slot in the bottom of the hole in the spindle, or collet, so that the cutter will be

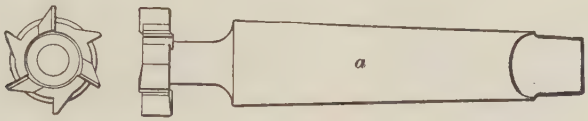


FIG. 12

positively driven. All shank cutters must be driven home quite heavily, using a lead hammer for the purpose; otherwise, the vibrations due to the cutting operation will soon loosen the cutter and, in consequence, it will dig into the work. When driving solid T-slot cutters home, a piece of round brass, copper, or soft iron should be held against the plain part on the end of the cutter to receive the blow, for if the blow falls on the teeth at one side of the center only, the cutter may be broken from the shank.

ANGULAR MILLING CUTTERS

45. An **angular milling cutter** is a cutter intended for the finishing of surfaces at an angle other than 90° to the axis of rotation. Angular cutters are made in a number of ways, and may be solid or have inserted teeth or blades. They may be driven by clamping them on an arbor or by screwing them on a shank or on the spindle. They may also be made solid and with a shank that is either tapered to fit the spindle or that is cylindrical; in the latter case, the shank is held in a chuck. Angular cutters are divided into two general classes, namely, *single-angle cutters* and *double-angle cutters*.

46. A **single-angle cutter** is one in which one cutting face is at an inclination other than a right angle to the axis of rotation.

Such cutters are known according to the angle included between the inclined face and a line square to the axis, as *30° single-angle cutters*, *45° single-angle cutters*, etc. The single-angle cutters are largely used for cutting the teeth of milling cutters, counterbores, hollow mills, and similar work having straight cutting edges.

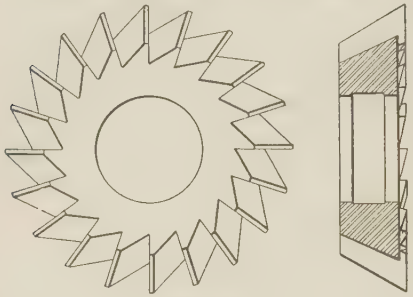


FIG. 13

47. The single-angle 60° cutter shown in Fig. 13 has teeth cut on its side as well as on the angular face. Such a cutter can operate on two surfaces at the same time; that is, it can cut on a surface square to the arbor and also on a surface at an inclination to it. Single-angle cutters intended only for finishing a surface at an inclination to the arbor are made without teeth on the side; such cutters are considerably cheaper than the one shown in Fig. 13.

48. A **double-angle cutter** has two cutting faces, each at an angle other than 90° with the axis. When both faces make the *same* angle with the axis, the cutter is named by giving the angle included between the two cutting faces. For instance, if the included angle is 60°, the cutter is called a 60° double-angle cutter. When the two cutting faces do not make the same angle with the axis, as, for instance, in the cutter shown in Fig. 14, the cutter is designated by giving the angle included between each face and a line square to the axis, as the angles *a* and *b*. For instance, if the lesser angle *a* is 12° and the greater

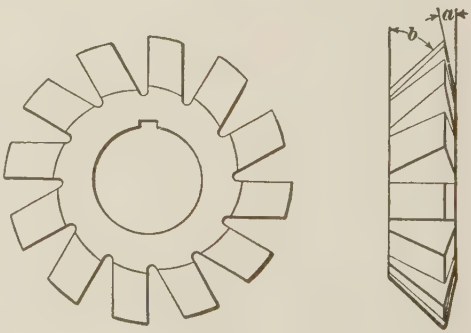


FIG. 14

angle *b* is 48°, the cutter is called a *12° and 48° double-angle cutter*. If the angle *a* is 30° and the angle *b* is 30° the sum of the two angles, which is the included angle, is 60°, and the cutter is called a *60° double-angle cutter*.

49. Double-angle cutters are most commonly used for fluting taps, reamers, milling cutters with helical teeth, and similar

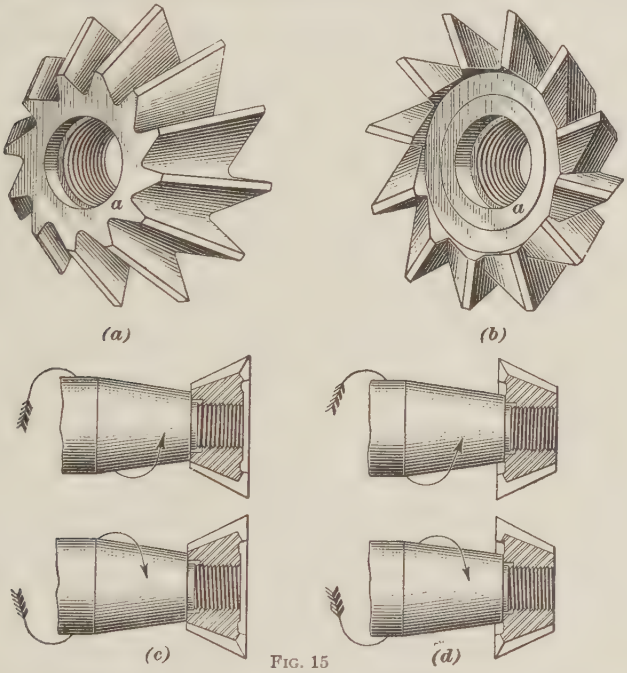


FIG. 15

work in which it is important that the two surfaces operated on at the same time be finished equally well. It is employed also for milling straight angular grooves. It must not be inferred that a surface at an angle to another one can only be finished with an angular cutter. In many cases, the work may be chucked in such a manner that a plain cutter or a side milling cutter may be used, and in other cases, the axis of rotation of the cutter is adjustable by using the vertical milling attachment, which allows a plain cutter or a side mill to be used for angular cuts.

50. Hand and Angle of Angular Cutters.—The hand and angle of an angular cutter may easily be determined by placing the cutter in such a position that the side that bears against the arbor is turned toward the observer. Then, if the thread is left hand and the top teeth must revolve toward the left in order to cut, the cutter is a left-hand cutter. If, with the cutter in this same position, the thread is right hand and the top teeth must move to the right to cut, the cutter is right hand. In Fig. 15 (*a*) and (*b*) are shown two angular cutters, the faces *a* of which bear against the arbor. As the top teeth must turn to the left in each case, to make the cutter work, these are left-hand cutters.

51. The angle of an angular cutter is said to be right hand or left hand, depending on the direction of slope of the angular face. If the smallest diameter of the cutter is at the side that bears against the shoulder on the arbor, the cutter has a left-hand angle; and if the greatest diameter of the cutter is at the side that bears against the shoulder the cutter has a right-hand angle. In Fig. 15 (*c*) are shown two cutters with left-hand angles, the upper being a left-hand cutter and the lower a right-hand cutter. In (*d*) are shown two cutters with right-hand angles, the upper being a left-hand cutter and the lower a right-hand cutter. The direction in which each cutter must turn is indicated by an arrow.

END MILLING CUTTERS

52. The **end mill**, sometimes called a *shank cutter* or a *stem mill*, is made with a taper shank *a*, Fig. 16, to fit the taper socket

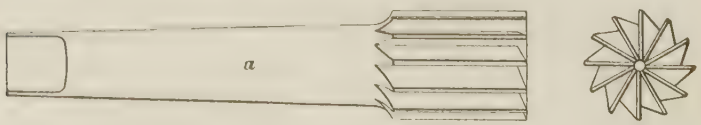


FIG. 16

in the machine spindle. Cutting teeth are formed on the circumference and also on the end, as shown. Large end mills

are usually made in the shell form, as shown in Fig. 17, and are used on shell-mill arbors. Very small end mills are constructed with either taper or straight shanks. Small end mills with straight shanks are held and driven by special collets or by universal chucks. End mills are designed primarily to cut on the end or when work is fed lengthwise of the cutter; but they are very largely used for making cuts at right angles to the cutter axis. The teeth are made coarse or fine, and straight or spiral, depending on the class of work to be done.

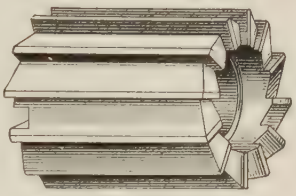


Fig. 17

53. The **center-cut end mill,** shown in Fig. 18, differs from the ordinary end mill in that it has a coarser pitch of teeth, which allows much larger end teeth *a* to be used. The

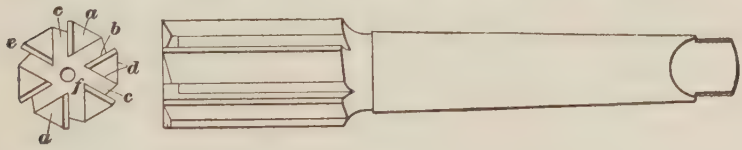


Fig. 18

faces *b* of the teeth are radial and large cuts *c* are made between the teeth to form good cutting faces and large spaces for the chips. The sides *d* of the teeth make the same angle with the cutting face. The cutter can be fed endwise into the work nearly to the depth of the teeth, and when the work is fed at right angles to the axis of the cutter, the outer ends *e* of the

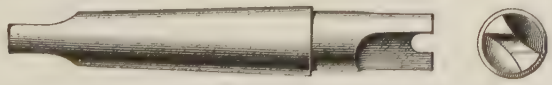


Fig. 19

teeth will cut away the metal in advance of the cutter while the inner ends *f* of the opposite teeth are cutting away the core. This cannot be done with the ordinary end mill shown in Fig. 16.

54. A peculiarly shaped mill usually considered as an end mill, although not very well adpated for cutting with its end, is shown in Fig. 19. This mill is known as a **cotter mill,** and is in reality a face cutter with two teeth opposite each other. It is particularly adapted for cutting narrow and deep grooves. It cannot be sunk endwise into solid metal to any extent, but a hole must be drilled where the groove is to start. The cutting is done by the edges on the circumference. As there is considerable room for the chips, the cutter will not clog very easily.

FORM AND FORMED MILLING CUTTERS

55. Any milling cutter intended for milling other than flat surfaces is called a *form milling cutter.* Form milling cutters are divided into the two general classes of *form cutters* and *formed cutters.* If cutters of both classes are of the same outline, they will cut the same shape. They differ mainly in that the outline of the form cutter is changed by grinding; whereas, the outline of the formed cutter is not changed.

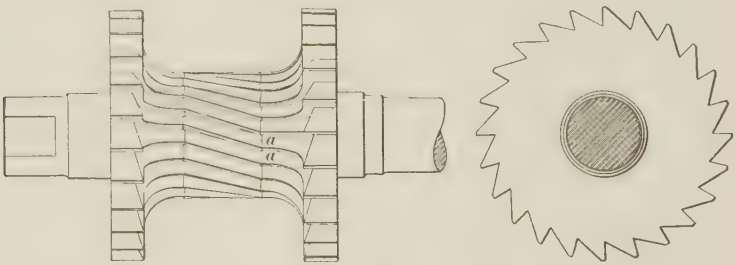


FIG. 20

56. Form Cutters.—The teeth of the form cutter are of fine pitch cut in the ordinary manner by the use of single-angle or double-angle cutters. The teeth are backed off by filing or by grinding the lands after hardening; but they can be sharpened but very little without changing their form or profile to some extent. The form cutter shown in Fig. 20 will cut the form or shape included between the two end cutters. It is a gang cutter consisting of three cutters assembled on the same arbor. The teeth of the three cutters are made to interlock,

as at *a*, so that a ridge, or line, will not be left where the cutters join, and to provide endwise adjustment so that the distance between the flanges of the cutters can be kept uniform after sharpening.

57. A **fly cutter** is a one-tooth form milling cutter that will exactly reproduce its own profile. In Fig. 21 is shown the simplest form of fly cutter with its own arbor. The arbor consists of a tanged shank *b* tapered to fit the miller spindle. The outer end is square on three sides and the back is rounded. A square slot for the cutter is made through the two opposite flat sides. The slot is far enough to one side of the axis that the front face of the cutting tool will be radial, or even with the axis of the arbor. The tool *a* is a piece of square steel filed or ground on one end to the required shape, and secured in the slot by two setscrews.

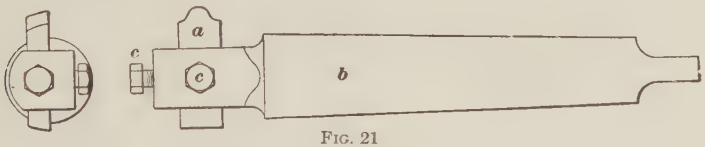


FIG. 21

Sometimes the fly cutter is turned to the required form when held as short as possible in the holder. It is given clearance by setting it farther out, in which position it becomes a formed cutter as well as a form cutter and can be ground radially on its face without changing the outline.

58. The fly cutter has the advantage of being low in cost, even when the profile is quite intricate; for this reason it is well adapted for such work as making forming tools for screw machines, making a gear with an odd pitch of teeth, and similar work that does not warrant the expense of a regular form cutter. As the cutter has only one cutting edge, it cannot be expected to last as well or to cut as fast as a regular cutter, but it will mill quite smoothly if kept sharp.

59. Formed Cutters.—A formed cutter is one so made that the sharpening of the teeth will not change their profile. The faces of the teeth are radial and the grinding must be

so done on the face as to retain this direction always. The most familiar formed cutter is the gear-tooth cutter illustrated in Fig. 22. The pitch of the teeth of formed cutters is usually

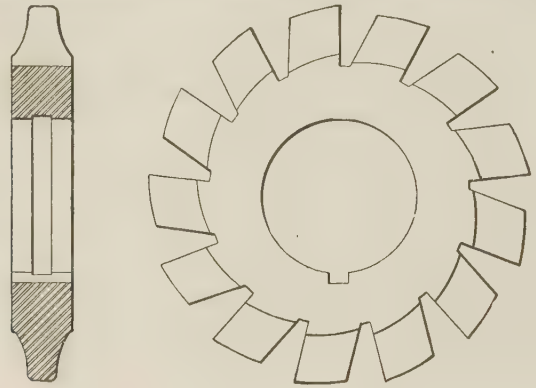


FIG. 22

two or three times that of form cutters. The slots forming the teeth are V-shaped.

60. One of the many profiles that may be made with formed cutters is shown in Fig. 23. In many cases, formed cutters may be combined with ordinary cutters or with form cutters; the several cutters when assembled will form a gang

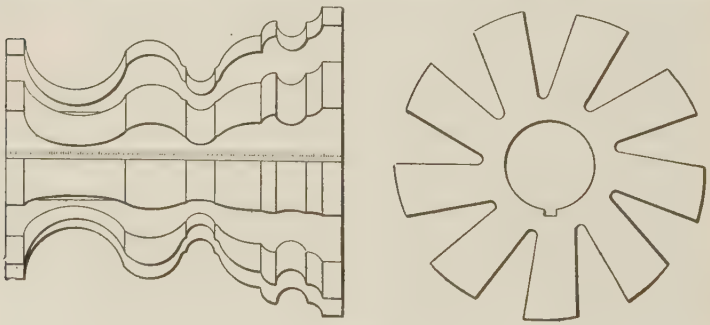


FIG. 23

mill. Formed cutters cannot be made without a special forming machine or special tools; for this reason they are usually bought of manufacturers who make a specialty of them. In

practice, a great variety of milling cutters will be found that at first will appear unlike any that have been illustrated here. When analyzed, however, they will invariably be found to belong to one of the several classes mentioned. In many cases the distinctive features of several classes may be combined in one cutter.

61. Interlocking Cutters.—If a cutter must maintain a fixed width or length and be adjustable after grinding, it is made interlocking. A form of interlocking cutter is shown in Fig. 24 (*a*). It is made of two pieces *a* and *b* that have interlocking teeth and that are held on the same arbor. The two

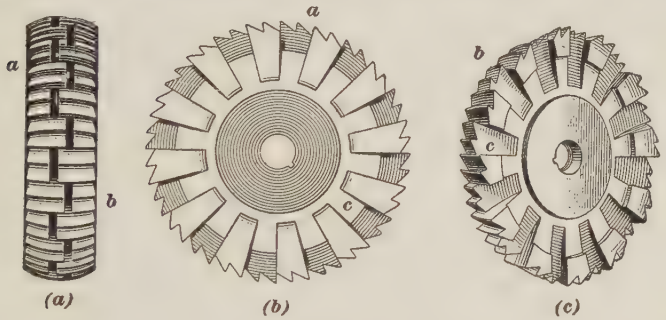


FIG. 24

parts *a* and *b* are shown separately in (*b*) and (*c*), respectively. Each is counterbored at the center and radial slots *c* are cut in the raised portion around the counterbore. The lands and spaces thus formed are equal, so that, when the two parts are brought together, the lands of one fit in the spaces of the other. Such cutters are used mainly for cutting slots or grooves that must have a fixed width. Gang cutters are also made with interlocking teeth, so that a line or ridge will not be formed on the work. After grinding, the cutter is adjusted to proper width by placing thin sheets of paper between the two parts before clamping them on the arbor. In view (*a*) the two parts are slightly separated to show more clearly the line of division.

CARE OF MILLING CUTTERS

62. Sharpness of Cutters.—If a milling cutter is to work to the best advantage, it is absolutely necessary that it be kept sharp, and that all cutting edges be at the same distance from the axis of rotation of the cutter. It is not sufficient that the cutting edges be at the same distance from the axis of the cutter, for if a true cutter is mounted on an arbor that runs out of true, the cutting edges will *not* be at the same distance from the axis of rotation. Consequently, some edges will have to do more work than others or the teeth on one side will do most of the cutting. When this is the case, the cutter can neither be pushed to the full limit of its capacity nor can it produce as smooth work as one that runs true in relation to its axis of rotation. This fact is becoming more generally realized, as shown by the increasing practice of grinding cutters while in place in the milling machine.

63. Effect of Dull Cutters.—Milling cutters cannot be ground true enough by hand to allow the machines to be worked to the best advantage. A cutter-grinding machine is necessary, and without it the milling machine is at a serious disadvantage. A dull cutter is distinctly a bad cutter, and should be sharpened as soon as it shows signs of becoming dull. It will do poor work, will require more power to drive it, and will wear out faster than a cutter that is kept sharp. The extra power required to drive a dull cutter is transformed by friction into heat, which tends to soften the cutting edges and to make them wear faster. In formed cutters there is also a wearing of the formed surfaces that will shorten the life of a cutter more than many sharpenings.

HOLDING AND DRIVING CUTTERS

64. Construction of Arbor.—The ideal method of driving the cutter is to make it a part of the spindle, and this is done to some extent in milling machines designed especially for side milling. In milling machines intended for general work, however, the cutter must be made so that it can be

removed easily, and consequently it cannot be made a part of the spindle. Cutters are most commonly clamped on the arbor that is driven into the spindle and is forced to rotate with it.

65. A common design of arbor is shown in Fig. 25. A taper shank *a* fits a corresponding hole bored in the spindle. The rear end of the shank has a tang *f* that enters a corresponding slot at the bottom of the tapered hole in the spindle, and that helps to drive the arbor. The part of the arbor that projects from the spindle is made cylindrical. A nut *c* is placed on the outer end for the purpose of clamping the cutter, which is placed between the removable washers *b*. These washers are made of different lengths to accommodate different widths of cutters, and also to allow the cutter to be placed in different positions along the arbor without the necessity of having a very large number of washers. The arbor is removed from the spindle

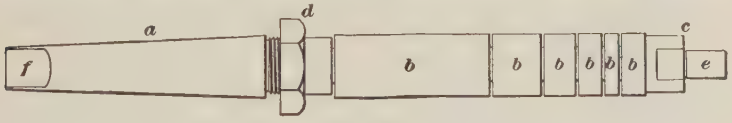


FIG. 25

by driving a tapered key through a slot in the spindle at the upper end of the shank. In some machines the spindle is hollow, and the arbor is then driven out with a rod. Sometimes the arbor has a nut *d* on a threaded portion at the front of the shank. By screwing this nut against the end of the spindle the shank may be forced out.

66. Supports for Arbors.—The front end of the arbor usually has a countersunk center to allow a dead center to be used for supporting it. The dead center is held in an adjustable outboard bearing *a*, Fig. 26, carried by the frame *b* attached to the outer end of the arm *c*. Occasionally, a cylindrical teat *e*, Fig. 25, is formed at the front end. This teat runs in a bushing held in the outboard bearing and serves to support the arbor. For very heavy cuts the arbor is sometimes supported by a central bearing *d*, Fig. 26, carried by the arm *c*. This bearing fits over one of the washers near the middle of the arbor and

thus supports the arbor. Cutters may then be used on each side of the bearing *d*.

67. The adjustable tie frame *b*, Fig. 26, clamps the arm *c* and the knee of the machine together and adds greatly to the stiffness of the machine. When the machine has no outboard bearing, the cutter should invariably be placed just as close to the spindle as circumstances will allow, as an arbor is comparatively slender and will spring considerably even under a moderate cut. When no way of steadying the end of the arbor is available, then in cases where the cutter must be placed near the end, the finishing must be done by light cuts, to keep the spring of the arbor within reasonable limits.

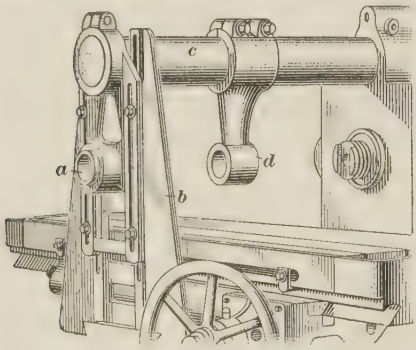


FIG. 26

68. Methods of Driving Cutters—Milling cutters held on arbors and used for light work are driven by the friction created between the cutters and the washers by screwing up the nut on the threaded end of the arbor. Most cutters and arbors are provided with keyways, so that square keys can be used to drive the cutters when cuts are heavy. Sometimes a half-round keyway is used in both the cutter and the arbor, and a piece of round steel, such as a piece of drill rod, is slipped in for a key to drive the cutter. Other cutters are threaded in the hole with a thread that has the same direction as that in which they are to rotate, and are screwed on arbors similarly threaded. The pressure of the cut then holds them securely. Regular arbors of the form shown in Fig. 25 are made with right-hand or left-hand threads, according to the direction in which the cutter must revolve. The direction in which the cutter must revolve is fixed and determines the hand of the thread on the arbor to be used; that is, it is necessary to select an arbor threaded so that slipping of the cutter will *tighten* the nut. If the cutter

is to run left hand, the thread on the arbor should be left hand, and if the cutter is to run right hand, the thread should be right hand.

69. Shell-Mill Arbor.—Large end mills are often made to be held in a manner resembling that in which a shell reamer is held, in which case the shell-mill arbor shown in Fig. 27 (*a*) is used. This arbor has a taper shank to fit either the milling-machine spindle or a collet fitted to the spindle. The shoulder at the end of the cylindrical part *a*, which forms the seat for the cutter, has two projections that enter corresponding slots in the cutter and insure positive driving. The cutter is confined lengthwise by the head of the screw *b*, which enters a counterbore in the cutter, thus bringing the head below the

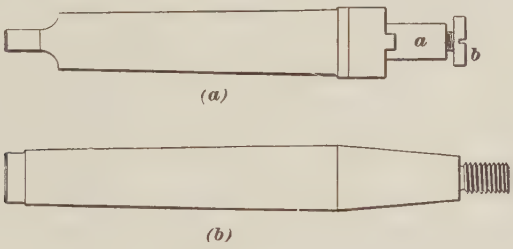


FIG. 27

teeth of the cutter. This is necessary for end milling and some kinds of side milling.

70. Screw Arbor.—Small cutters are often made with threaded holes and are screwed on a screw arbor made as shown in Fig. 27 (*b*). The direction of rotation of the cutter that can be used with a screw arbor is determined by the direction of the thread of the screw *b*, at the end of the screw arbor. That is, for a left-hand thread use a left-hand cutter; for a right-hand thread use a right-hand cutter.

71. Effect of Vibration.—In an arbor driving a cutter by positive means, as by a key, or by projections on the shoulder, there is no danger of the nut unscrewing by a slipping of the cutter; but the vibrations due to the cutting operation tend to unscrew the nut, or the screw *b*, Fig. 27 (*a*), unless its thread

is in accordance with the statement made in the preceding article. If no cutter having the proper direction of rotation is available, the nut or screw must be screwed home as firmly as possible, and the chance of the cutter working loose must be taken. Shell-mill arbors and screw arbors are liable to become loose for the same reasons as the ordinary arbor, and the same care must be used with them.

72. Arbor for Use Between Centers.—A milling arbor may be made as shown in Fig. 28 if the cutter is to be driven between centers, as occurs when a lathe is temporarily converted into a milling machine. The arbor is driven by a dog, the tail of which engages with the face plate. Such an arbor may be used for a regular milling machine having index centers. One or more pieces of work are clamped on the arbor and milled

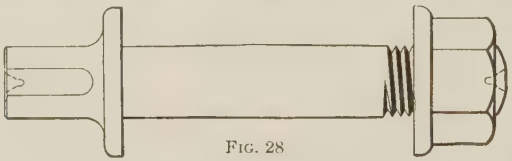


FIG. 28

around the end, as in finishing a crank, or on the six sides, as when finishing hexagonal nuts.

73. Care of Arbors.—When the end of the arbor is supported either by a bushing or by a dead center, the arbor cannot work out of the spindle if the supports are properly adjusted. When the end of the arbor is free, however, it must be driven home firmly in the spindle, or it will come loose under vibrations due to the cutting operation. Before inserting the arbor, the hole in the spindle should be thoroughly cleaned of any chips, grease, or oil. The shank of the arbor must be cleaned off just as carefully, inserted so that the tang enters the corresponding slot in the spindle, and driven home by a fair, quick blow with a heavy lead hammer. The coming loose of the arbor, which is here assumed to have been properly fitted, is nearly always due to oil or grease on the shank and in the spindle. Hence, if the arbor persists in coming loose, again clean the shank and spindle thoroughly. If the shoulders of the tang

strike the bottom of the hole in the spindle, the arbor cannot be driven home properly, in which case the tang should be examined to find the cause, and the shoulder should be ground off where it bottoms. Chips or dirt between the collars may bow the arbor and cause it to run out. An arbor that runs out of true should be repaired or replaced by a new one.

74. Plain Collet.—A collet is a socket or taper bush used for bushing down the hole in the milling-machine spindle so that smaller arbors or shanks can be held. Fig. 29 (*a*) shows how such a collet is usually made. The outside fits the taper in the milling-machine spindle and the inside is bored true with the outside, so that an arbor inserted in the collet will run true when the collet is in the machine. The tang of the arbor or of the cutter shank projects into the slot *a*, and the arbor can be removed from the collet by driving a taper key into the slot behind the tang.

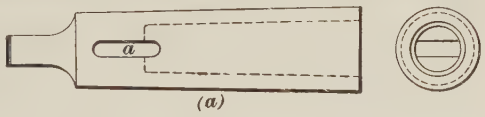


FIG. 29

75. With constant use, a collet will enlarge somewhat inside, so that the shank of the arbor or cutter will finally bottom. A piece of writing paper may then be wrapped around the shank; the paper must not lap, however. While this is a makeshift at best, it is one that will often prove very handy. A key to drive the shank out after it is driven home is usually made tapering, as shown in Fig. 29 (*b*). A hole is drilled near the large end so that a chain can be attached to the key and to some stationary part of the machine, to prevent it from being lost.

76. Chuck Collet.—Small cutters are often made with cylindrical shanks, and very small cutters are made from drill rod. Such cutters may be held by means of the chuck collet shown in Fig. 30. The front end of the collet is bored cylindrical, and so that the axis of the cylindrical hole coincides with the axis of the shank *a*. A nut *b* having a plain tapered

part is fitted to the front end, which latter has been split into three parts. As the front end is tapered on the outside, the screwing up of the nut *b* will close the split part on the shank of the cutter, thus holding it central. The chuck collet shown is open to one objection, which is that all cutters to be used with it must have the same diameter of shank. If a cutter holder is required to take straight shanks of varying diameters, a high-grade drill chuck may be attached to a shank fitting the milling-machine spindle.

77. Chucks and Face Plates.—A self-centering lathe chuck may be fitted to the spindle to hold cutters having larger shanks than the drill chuck will receive. For some work a single-tooth cutter may be mounted in a slot of a face plate fitted to the spindle. Such a construction does not differ essentially from that of a fly cutter, being simply a fly cutter on a larger scale. A cutter attached to a face plate will be found of service in finishing a surface to a circular profile having a given radius. Although this can be done to the best advantage with a regular milling cutter made especially to the required radius, in many cases the expense of making such a cutter is not warranted by the conditions, and a face-plate cutter will then prove an excellent and inexpensive substitute. The general construction of a face-plate cutter and its similarity to the fly cutter are shown in Fig. 31. The face plate *a* is threaded so as to screw on the spindle. The cutter *c* is adjustable in the slot *b*, and can be clamped by tightening the nut *d*. The shank of the cutter should have a rectangular cross-section, so that the cutter will not turn in the slot.

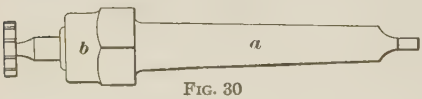


FIG. 30

78. If a circular milling cutter of the right profile, but of smaller diameter, is available, the expense of making a single-tooth cutter can often be saved by clamping the regular cutter to the face plate, passing the clamping bolt through the slot in the face plate. The cutter is then placed with one of its cutting edges in the position occupied by the cutting edge of the fly cutter shown in Fig. 31, and after adjusting it to the

required radius it is clamped. Any ordinary bolt may be used for clamping. The setting of the cutter so as to mill a given radius is not a particularly difficult matter. The cutting edge must be set at a distance from the circumference equal to the difference between the required radius and the radius of the face plate. When the cutter projects considerably from the face of the face plate, the blade of a try square may be placed

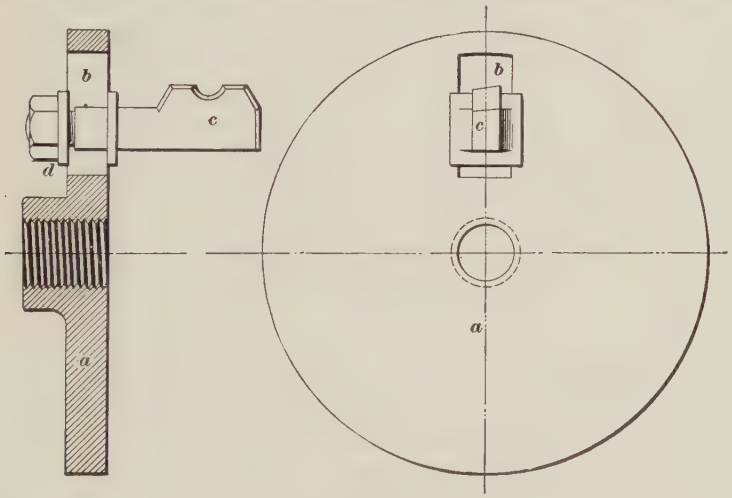


FIG. 31

on the cutting edge and the stock held against the face plate; the distance from the edge of the blade to the circumference may then be measured with a steel rule. When a regular milling cutter is used as a fly cutter, it is advisable to drive a dowel-pin into the face plate in such a position that it will come between two teeth, and thus prevent rotation of the cutter under the pressure of the cutting operation.

CUTTING SPEEDS AND FEEDS

79. Conditions Governing Cutting Speed.—Owing to the large variety of work that may be done by milling, no hard and fast rules in regard to proper cutting speed and feed can be given. When much work of the same kind is to be

done, it is well to experiment, starting with a feed and speed that judgment indicates to be safe, and varying both gradually until the greatest production at the least expense per piece has been obtained.

80. The cutting speed depends on several things, one of which is the kind of material to be milled. As a general rule, the harder the material the slower must be the cutting speed. Thus, unannealed tool steel calls for a low cutting speed, but soft brass castings can be advantageously milled at a much higher speed. To aid the milling-machine operator in judging about where to commence to experiment, the average cutting speeds for different materials are here given. These speeds are the surface speeds of the cutter, or the speeds of points on the outer edges or faces of milling cutters; for a point near the center of a cutter will not travel so fast as a point near the outer edge.

81. A surface speed of 15 feet per minute can rarely be exceeded for unannealed tool steel; but if the steel is well annealed, the speed may be increased to 25 feet per minute. Wrought iron and soft machinery steel can be successfully machined at a speed of from 30 to 40 feet per minute. Medium-hard iron castings, phosphor bronze, Tobin bronze, aluminum bronze, and similar copper alloys may stand a cutting speed of 50 feet per minute, though a very slow speed is required for some tough copper alloys. A speed of 60 feet per minute may be used for common, soft gray-iron castings, soft-steel castings, and malleable-iron castings. Red-brass castings, commonly called gun-metal castings, can be machined at a cutting speed of 80 feet per minute, and this can be increased to 100 feet for yellow brass. The foregoing speeds may be used if the cutters are made of carbon steel; but if high-speed-steel cutters are used, these speeds may safely be doubled.

82. Another factor in the selection of a proper cutting speed is the presence or absence of provision for carrying away the heat generated in the cutting operation. This heat may be carried away by flooding the work and cutter with oil or soda

water during the milling operation. When this is done while a sharp cutter is used, the cutting speed may be as much as 50 per cent. in excess of that possible with dry milling.

83. A sharp cutter will easily stand a higher cutting speed than a dull one, and in this respect a milling cutter is similar to a lathe tool. The duller the cutter, the more heat will be generated per revolution; consequently, to allow this heat to dissipate into the work and surrounding atmosphere so that the cutting edges will not become overheated, the revolutions per minute must be lowered.

84. Calculation of Cutting Speed.—The cutting speed of a milling cutter, that is, the speed in feet per minute of a point on its outer surface, or edge, may be found by the following rule:

Rule.—*To find the cutting speed of a milling cutter, in feet per minute, multiply 3.1416 times the diameter of the cutter, in inches, by the number of revolutions per minute of the cutter, and divide the product by 12.*

EXAMPLE.—A cutter 3 inches in diameter makes 120 revolutions per minute. What is its cutting speed in feet per minute?

SOLUTION.—Applying the rule, the cutting speed is

$$\frac{3.1416 \times 3 \times 120}{12} = 94.25 \text{ ft. per min.} \quad \text{Ans.}$$

85. Conditions Governing Rate of Feed.—The rate of feed depends on the pitch of the teeth, the provision made for clearing out the chips, the rigidity of the work and of the machine, the manner in which the work is held, and the degree of finish desired. The first milling cutters were constructed with teeth having a very fine pitch. Experience quickly showed that the chips would clog up the spaces between the teeth, packing in so closely that the cutter would work only when a very fine feed was employed. It became gradually understood that by making the pitch of the teeth coarser, a distinct chip could be taken, whose size, so far as the cutter was concerned, was limited only by the size of the space between the teeth and the provision made for clearing out this space.

86. Cutters for slotting screw heads have a very fine pitch of teeth. They stand a rapid feed, however, because the slots are shallow and the cuts are short. Slitting cutters require very much coarser teeth, as they often take deep cuts with considerable feed, which demands a very much greater chip space between the teeth. Alloy-steel cutters to be used with high feeds should be made with a coarse pitch of teeth to hold a great many chips and of such design that chips will not stick in them. Other conditions permitting, the rate of feed per tooth can be greater as the pitch of the teeth is made larger.

87. The rigidity of the work—that is, its resistance to a change of form under the pressure of the cutting operation—has a great influence on the rate of feed. If the work springs easily, a fine feed must be employed; if it is very rigid, the feed can be increased up to the limit. A coarser feed is permissible when the work is firmly held than when it is lightly held.

As stated before, the allowable feed is influenced largely by the space available between the teeth to receive the chip. Evidently, this space can be filled either by a heavy and short chip or by a fine and long chip of equal volume. Therefore, for a shallow roughing cut the feed may be coarse, and an increase of the depth of the cut requires a decrease of the feed.

88. The degree of finish desired largely influences the choice of feed. As a general rule, a relatively low cutting speed and a heavy feed will be found advantageous for roughing out, and for finishing, a higher cutting speed and a fine feed are needed. The only exception is in the case of side milling with inserted-tooth or inserted-blade cutters. Here a wide, flat-nosed cutting edge can be used, and, consequently, a wide feed.

Another point that must be taken into consideration, when experimenting for a proper feed and cutting speed for a particular job, is the difficulty of resetting some forms of gang cutters after sharpening so that they will cut exactly the same shape as before. In such cases, it will occasionally prove more economical to use a slower speed and lighter feed to make the cutter last longer and thus save the time required for resetting it after it has been sharpened.

MILLING-MACHINE WORK
(PART 2)

OPERATION OF MILLING MACHINE

SELECTION OF CUTTER

CONDITIONS GOVERNING CHOICE

1. The selection of a milling cutter is a matter that depends not only on the nature of the work, but also on the construction of the machine, the attachments to the machine, the stiffness of the work itself, the manner in which it is held, and the cutters that are available. For instance, if a large surface of a rather springy casting is to be finished by milling, it will often be out of the question to use a wide plain cutter, because the pressure of the cutting operation, even with a very fine cut, may be sufficient to spring the work seriously. But, if a small end mill is used, it may be possible to make a very satisfactory job of machining the casting.

Some machines are so constructed that only side or face milling cutters can be used, and, consequently, the operator has no choice of a cutter. Other machines have no outboard bearing to support the arbor; it would be a mistake to select a wide plain cutter for finishing a wide flat surface in such a machine, as the spring of the arbor even under a very light cut might be sufficient to condemn the work. A side mill or an end mill would probably prove satisfactory under such circumstances.

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2. When surfaces parallel to the line of motion are to be finished at an angle to each other, it is a question of attachments, cutters, and type of machine available. For instance, in a plain milling machine it may be possible to do the work only by the use of angular cutters; in a universal milling machine, when the job may be held between centers, it might be done by a plain cutter or an end mill.

3. When the choice has narrowed down to a certain type of cutter, the question of which kind of the chosen type of cutter will remove the most stock at the least expense often becomes a very pertinent one. Suppose that it has been determined that a plain cutter is to be used. If the surface is narrow, a straight-tooth cutter should be selected; but if the removal of a large amount of stock from heavy work is required, a nicked cutter or an inserted-tooth cutter would be chosen.

4. When it is a question of whether a plain mill, a side mill, or an end mill is to be used, it is to be observed that for side milling and end milling less power is usually required. Furthermore, when the cutter must pass over slender or pointed parts of the work, there is less springing and less breaking of the edges with a side cutter or an end cutter than with a plain cutter. On the other hand, the plain cutter will usually do the work in less time, and should be used, other circumstances permitting.

5. In the case of grooving, if the groove is straight, it can usually be cut cheapest by plain cutters, slitting cutters, or formed cutters, depending on the profile of the groove. When it follows a helical path, it can be cut by an end mill, a form cutter, a formed cutter, or an angular cutter; when the cross-section of a helical groove is required to be rectangular, a plain milling cutter or slitting cutter cannot be used, but an end mill must be employed instead. When a groove following an irregular path is to be cut, an end mill will almost invariably have to be used, although a plain mill or a formed mill may occasionally be employed for part of the groove.

From the foregoing statements it will be seen that the selection of a cutter is a matter of judgment, which must be based on practical experience with different milling operations.

DIAMETER OF CUTTER

6. The diameter of the cutter has an influence on the length of time required to machine a surface. As a general rule, it may be stated that, with equal rates of feed and the same speeds in revolutions per minute, a cutter of small diame-

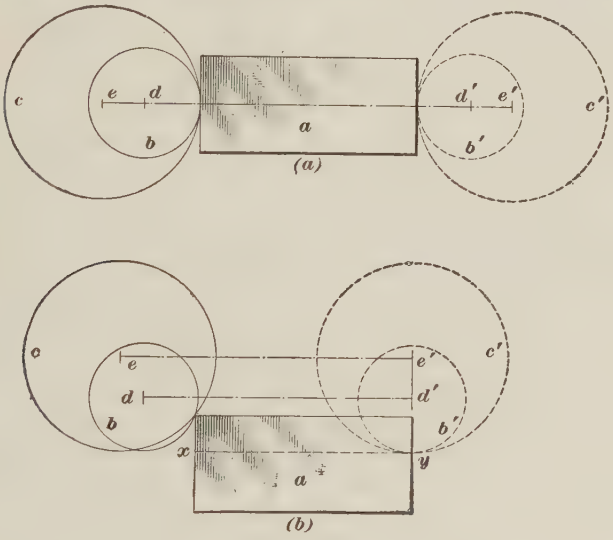

FIG. 1

ter will pass over a surface in less time than a cutter of larger diameter, because it will need to move a shorter distance. For example, in Fig. 1 (*a*) the surface *a* is to be machined by an end mill. If the smaller cutter *b* is used, it will move across the work to the position *b′*, and its center will travel from *d* to *d′*; but if the larger cutter *c* is used, it will have to travel to the position *c′*, or a distance equal to *e e′*. As *d d′* is much shorter than *e e′*, the smaller cutter will travel a shorter distance than the larger one in passing over the same surface.

The case shown in (*b*) represents the piece of work *a* as being cut down to the line *x y* by two different sizes of plain mills *b* and *c*. In this case, also, the smaller cutter travels the shorter distance *d d'* while the larger must travel the distance *e e'* to do the same work.

7. It must not be assumed from the foregoing that, if one cutter is smaller than another, the work can be machined quicker in every case by using the smaller cutter. It is only when circumstances permit equal, or nearly equal, rates of feed per minute that the smaller cutter will have the advantage. Under these conditions, on some classes of work a saving as high as 10 per cent. may be effected in the time by the difference of only $\frac{1}{2}$ inch in the diameters of the cutters. It is well to bear in mind that the saving effected by the use of the smaller cutter is greater for short work than for long work.

8. The smallest size of cutter that can be used is naturally governed by practical considerations. Thus, an end mill must be sufficiently stiff to stand a fair cut without bending; in the case of a plain mill, the advisability of leaving sufficient stock around the hole of the cutter governs its smallest permissible size. Again, a short cutter can usually be smaller than a very wide cutter, as the stresses to which the cutter is subjected by the cutting operation will, as a general rule, be less severe with a narrow than with a wide cutter.

LUBRICATION OF CUTTERS

9. Purposes.—Ample lubrication of a milling cutter during the cutting not only decreases the friction and thus lessens the heating of the work and cutter, but also carries the heat away to an extent depending on the character, volume, and method of applying the lubricant. Carrying away the heat is probably the chief benefit derived from an ample application of lubricant, experience having shown that keeping the cutting edges cool largely prevents them from becoming

dull. A proper application of the lubricant will also quite effectively prevent the chips from filling up the spaces between the teeth of the cutter, and will consequently permit an increased rate of feed.

10. Materials Requiring Lubrication.—Experience has shown that no lubrication is required for milling ordinary gray cast iron, yellow-brass castings, and babbitt. For milling wrought iron, steel, steel castings, malleable-iron castings, bronze, copper, and the various tough copper alloys, lubrication of some sort is usually either necessary or advisable.

11. Kinds of Lubricants.—The lubricant generally used for milling cutters is either an oil or a mixture of oil with soda water and other ingredients. While oil alone is probably the best lubricant, it is also the most expensive; for this reason, it is rarely used for any other than small, fine milling, where ample provision may be made for catching most of the surplus oil and the chips. A cheap mixture of oil with other ingredients is usually preferred for cases where the surplus oil cannot readily be saved.

12. Pure lard oil is the best lubricant for milling cutters, as it has sufficient body to make it adhere well; furthermore, it thickens very slowly from age and use. Its only drawback is the comparatively high cost. Some of the fish oils are considerably cheaper than a good grade of lard oil, and are considered by some to be fair substitutes. If most of the drippings and chips are caught, the oil may be separated by an oil separator, in which case a high-priced lard oil will often prove the cheapest in the long run, as its superior lubricating qualities enable more work to be done.

METHODS OF LUBRICATION

13. The method of applying a lubricant naturally depends on the service in which the machine is engaged. When only a few pieces are to be milled, an expensive lubricating system is scarcely advisable; when the machine is constantly employed

on duplicate work, such a system will usually soon pay for itself by reason of the decrease in cost of maintenance of cutters and increase in production. The different methods of applying a lubricant to a milling cutter are by a brush, by a gravity feed, and by a pump.

14. Lubrication by Brush.—The simplest method of lubrication consists in applying the lubricant to the cutter with a brush. This method is well adapted to delicate work where light cuts are taken. The oil supply being intermittent in this case, it must be frequently renewed, the chips at the same time being cleared out from between the teeth of the cutter. The brush should always be applied to the side of the cutter that runs away from the work, thus avoiding all danger of its being drawn toward the work by the cutter. A stiff, short-handled bristle brush, called an oil brush, or else a small paint brush, is preferable for this work.

15. Lubrication by Gravity.—Constant lubrication is generally preferable to intermittent lubrication. For this purpose a can or a small tank may be placed at some distance above the cutter and a bent drip pipe with a stop-cock in it used to convey the lubricant to the top of the cutter. The rate of flow is then adjusted by turning the stop-cock. Such a tank is furnished with most milling machines; many machines have the table designed with oil pans to catch all the drippings and chips. The lubricant is then drained off, and after being strained or otherwise purified, it may be used again.

16. When no provision has been made for catching the drippings, a suitable drip pan, easily made from a piece of sheet tin, bent up to form a box, may be placed under the work. A piece of brass wire gauze having about sixty meshes to the inch may be soldered to a frame placed in the drip pan, so that the gauze is about 1 inch above the bottom of the pan. The lubricant will thus be strained automatically to a fairly satisfactory extent; as soon as the drip pan is full, the strainer with the chips is lifted off and the lubricant is poured into the tank.

17. Lubrication by Pumping.—A constant stream of lubricant will keep the cutter sharp for a greater length of time, and will also wash out the chips. This fact has gradually become so well recognized that it is becoming quite universally the practice to pump the lubricant on the cutter in a constant stream under a light pressure. A rotary force pump, driven

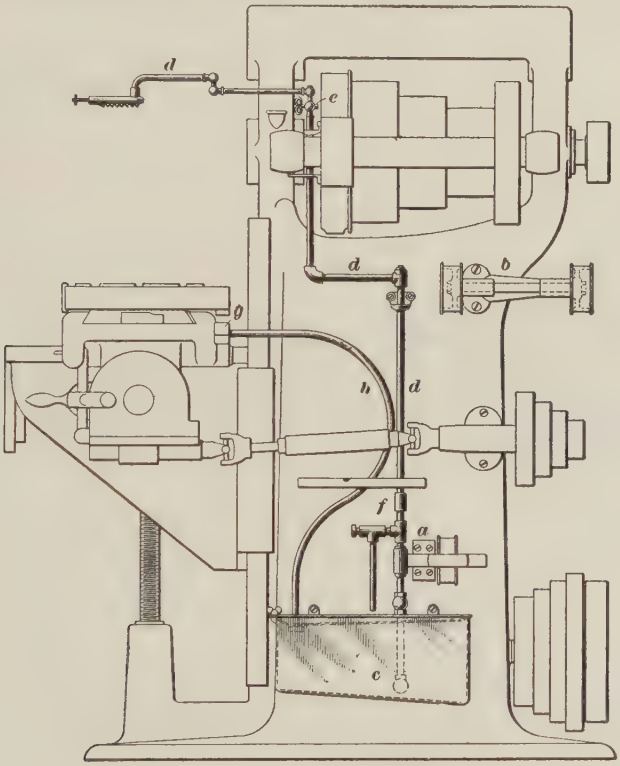

FIG. 2

directly from some rotating part of the machine, is generally used. The lubricating arrangement adopted by one manufacturer for a machine intended for fairly heavy milling is shown in Fig. 2. A pump *a* is attached to the frame of the machine and is driven by a belt from a pulley on the bracket *b*, which is bolted to the frame. The shaft of this

pulley is in turn driven by a belt from the overhead countershaft. The suction pipe of the pump enters the tank *c* holding the lubricant, which is pumped through the pipe system *d* and is delivered directly on the cutter. The upper end of the delivery pipe has swivel joints so that it can be adjusted to deliver the lubricant where it will be the most effective on cutters differing in size and position. The quantity of lubricant that is discharged can be regulated by the stop-cock *e*.

18. The pump *a*, Fig. 2, runs at a constant speed and consequently delivers a constant volume of lubricant. When less than this quantity is used, the rising of the pressure in the pipe system will open the relief valve *f*, and the excess will pass back into the tank. In the machine shown, a gutter extends around the table, from which the lubricant drains

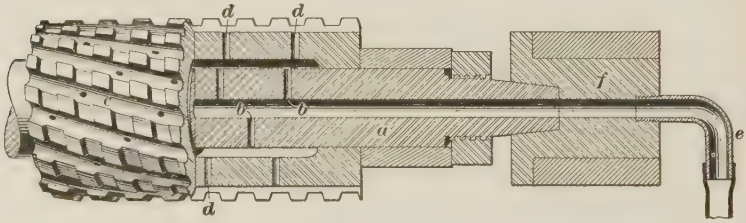

FIG. 3

into the trough *g*, and then through the flexible tubing *h* back to the tank. The lubricant is thus used over and over again; the only portion lost is that adhering to the chips, and a large percentage of this can be recovered by the use of a separator. When the lubricant is supplied in a constant stream, it is well to discharge it as close to the cutter as circumstances permit, to prevent splashing; it should be so delivered that the issuing stream will tend to wash the chips out of the cutter and away from the cuts.

19. Internal Lubrication of Cutter.—One form of internally lubricated cutter is shown in Fig. 3. The arbor *a* has drilled into it a center hole that extends nearly to the shoulder against which the cutter is clamped. A number of radial holes *b* are drilled through the arbor, to connect its

central hole with the recess within the cutter *c*. Several holes *d* are drilled in the tooth spaces through the shell of the cutter. The lubricant is pumped through a tube *e* into the arbor and issues in fine streams through the holes *d*, thus effectually clearing the cutter of chips and applying the lubricant where it is most needed, that is, directly to the cutting edges. The end of the arbor is tapering, and fits a tapered hole of the stationary bushing *f*, which is placed in the outboard bearing. This construction allows the arbor to revolve, but prevents any escape of the lubricant except through the radial holes in the arbor.

PREPARATION OF STOCK

20. Condition of Stock.—The term *stock*, when used in connection with a milling operation, refers to the work in its rough condition, consisting of castings, forgings, and bar stock cut to dimension. The success of the milling operation depends to a large extent on the condition in which the stock reaches the milling machine. If the stock is hard, either in spots or all over, as sometimes occurs with unannealed tool steel and often with forgings, or if the stock has a hard skin, as is usually the case with iron castings and steel castings, the hardness will cause the cutter to dull rapidly, which prevents the machine from being worked to the best advantage. In some cases, the stock is as soft as it can be made, and no further preparation is necessary. In other cases, the stock can readily be softened and thus be put in better condition for milling. The preparation may consist of a removal of hard scale by pickling and rattling, or uniform softening by annealing, or maybe a combination of these methods.

21. Removal of Scale.—Iron and steel castings, when they leave the mold, usually have a hard glassy skin, or *scale*, as it is called, in which sand is frequently embedded. This scale, when the size of the casting allows, can be pretty thoroughly removed by rattling the castings in a foundry *rattler*, or *tumbler*. Castings of a size and shape that prohibit tumbling

may have the scale softened, so that it will crumble easily, by *pickling*. The castings to be pickled are placed for from 10 to 15 minutes in an acid bath composed of 1 part of sulphuric acid to 25 parts of boiling water. After being pickled, the castings must be thoroughly washed in clean boiling water to remove all traces of the acid, which would cause them to rust very rapidly. A hard scale often found on forgings may also be removed by rattling or pickling.

22. Annealing.—When castings or forgings are found too hard to mill easily, even after the scale has been removed, they may be softened by heating them very slowly to a dull-red heat, and allowing them to cool very slowly. This annealing will have the further advantage of relieving, to a large extent, the internal stresses that have been set up in forging or casting. The extent to which the shape of the work will change after machining is thereby reduced.

HOLDING WORK

HOLDING WORK ON TABLE

23. General Principles.—The work may be held in the milling machine by attaching it directly to the table, by holding it in a vise, by holding it between centers, or in a chuck, or on an arbor held in the index head, and, finally, by means of special fixtures. No matter how the work is held, certain conditions must be fulfilled so that the machining can be done successfully. It must be held so rigidly that it cannot slip under the pressure of the cutting operation; it must not be sprung by the clamping; it must be so supported that it will not bend either under its own weight or under the pressure of the cut; and it must be lined up properly, so that the machining will take the required direction.

24. Holding Devices.—If circumstances permit, the work should be bolted directly to the table, by bolts with thin heads that will slip into the T slots. When this cannot

be done, clamps must be used. As the pressure due to the milling operation is usually much greater than that in planer work, the work must be held much tighter to prevent its slipping, and, generally, the clamps should be more rigid and the bolts heavier than would be required for the same job on the planer. Furthermore, a stop or stops should be used whenever possible. If the table has holes in it, pins similar to planer pins may be used; in the absence of holes, a parallel bar can usually be bolted directly to the table to form a stop, and the work can then be pushed against it.

25. Considerable care will often be required to clamp the work so that there will be no danger of its slipping, especially in vertical milling machines when the work attached to the table is intended to be machined all around its circumference at one setting. In such a case, the tendency of the work to rotate must be counteracted either by the friction caused by clamping or by stop-pins. The clamps, pins, screw plugs, dogs, and similar clamping devices used do not differ from the corresponding devices utilized in planer work. Neither is there any difference in their application, except that more attention must usually be paid to supporting the work on a milling machine than is required for a planer.

26. Use of Angle Plate.—A job may be clamped to the table of a plain milling machine of the pillar type by using an angle plate to hold the work square with the table, as shown in Fig. 4. The work *a* is a sliding table for a metal-working machine and has a dovetailed bottom that is to be accurately machined so that the bottom surfaces are parallel to the top. With this type of machine, this job of milling can be done only with end mills and an angular mill fastened to a shank, if the whole bottom is to be finished at one setting, which is necessary if all surfaces of the bottom are to be machined correctly. To do this, the work must be set up on edge, and as it would have but a very small bearing on the milling-machine table, an angle plate *b* can be advantageously used to insure that the bottom will be milled parallel to the top, and also to steady the work.

27. As the piece of work *a*, Fig. 4, has **T** slots in it, bolts can be slipped into these; they are then passed through the slots of the angle plate, to bolt the work to it. In case the

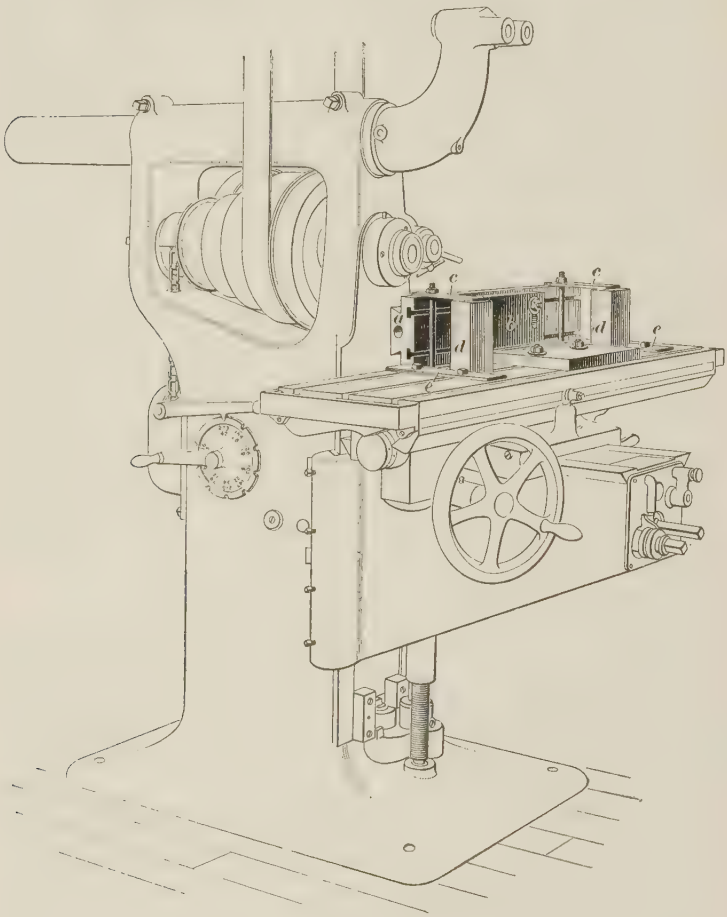

FIG. 4

angle plate has no slots that will come opposite the slots in the work, the latter could be attached by bolts and clamps to the angle plate. The work is held down on the milling-machine table by the clamps *c*, the rear ends of which rest

on packing blocks *d*. The pressure of the cutting operation in this case tends to overturn the work and also to slide it along the milling-machine table; the first tendency is resisted by the angle plate and the second by the stops *e*, which are bolted to the table in contact with the ends of the work.

28. Setting Work Square With Spindle.—Lining the work square with the spindle horizontally is accomplished, on the plain milling machine shown in Fig. 4, by lining the angle plate parallel to the line of travel of the table. This can be done by the aid of some suitable blunt-pointed tool that is held in the spindle. The table is run endwise until the marking point is near one edge of the angle plate, as, for example, the right-hand one; then, by means of the cross-feed screw in the knee, the table is moved toward the marking point until a piece of paper will just be nipped between the marking point and angle plate. The table is then run back until the marking point is near the left-hand edge of the angle plate. If the paper is not nipped again, the angle plate must be shifted. These adjustments and tests must be repeated until the paper strip is held with the same pressure at each end. The horizontal motion of the angle plate will then be at right angles to the spindle.

29. Setting Top of Work Parallel With Surface of Table.—On a milling machine arranged for plain or angular milling, as in Fig. 4, the surface gauge may be used to show whether the work is set parallel to the surface of the table. The base of the surface gauge is placed on the table and the bent end of the pointer is adjusted to a point at one end of the work, and is then moved to the other end and tried in the same manner. The work is so adjusted, if necessary, that the pointer will touch at each end with the same pressure. The top of the work will then be parallel with the table.

30. Lining Work With Table Motion.—When the sides or ends of work are to be lined up parallel with the travel of the table, the setting may be tested with a pointer clamped to the arbor in the spindle, traversing the work along the pointer, and adjusting it so that each end of the work is

either in contact with the pointer or measures the same distance from it. Sometimes a large try square may be used, in which case the beam of the square is placed against one of the edges of the table, and the work is adjusted even with the blade.

31. Clamping Work for Grooving.—Cylindrical work may be held on the table of a horizontal milling machine as

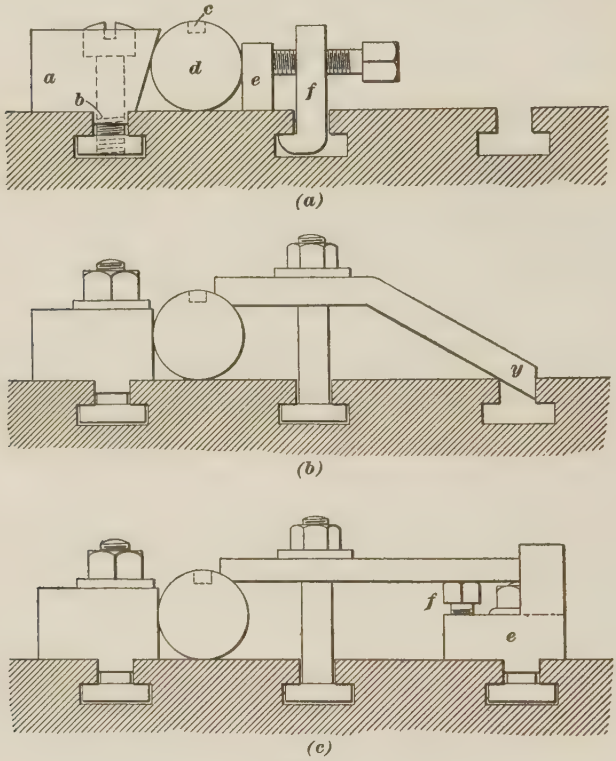

FIG. 5

shown in Fig. 5 (*a*) when a groove is to be milled parallel to the axis of the work. A milling-machine strip *a*, which has a tongue *b* at the bottom, is bolted to the table with the tongue in one of the **T** slots. The working surface of the strip is machined parallel to the line of motion of the table, so that any work placed against it is parallel to the line of motion.

Suppose that a keyway *c*, shown by the dotted lines, is to be cut the whole length of the shaft *d*. The holding devices must be clear of the cutter and are therefore placed in the positions shown. When the block *e* is tightened against the work by the screw plug *f*, the pressure will hold the shaft against the strip *a* and the table at the same time. The advantage of this method is that none of the holding devices extend above the surface of the work.

32. A shaft in which a keyway is to be cut may be held as shown in Fig. 5 (*b*). To prevent the shaft from slipping back, the clamp is bent and made of such a length that its rear end *y* will catch the edge of a T slot. The same object may be attained, as shown in (*c*), by the use of a special packing block *e*, which has a projection on it to prevent the clamp from moving, and is bolted to the table. The block may be adjusted for different heights of work by turning the setscrew *f*, on the head of which the rear end of the clamp rests.

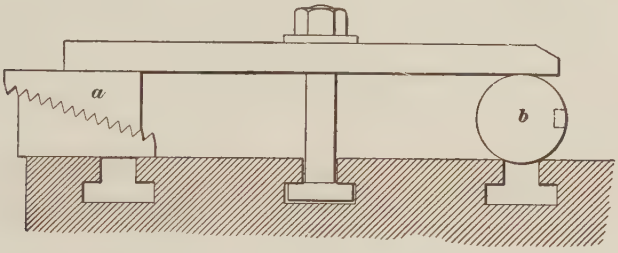

FIG. 6

33. Clamping Shaft in T Slot.—A shaft to be milled with an end mill in a horizontal machine, or with a plain slotting cutter in a vertical machine, may be held as shown in Fig. 6. The shaft *b* is placed in one of the T slots of the table, the edges of which, being parallel to the line of motion, will line the shaft properly. The packing block *a* is adjustable for height, being made in two duplicate parts, with saw teeth of about $\frac{1}{8}$- to $\frac{1}{4}$-inch pitch on their inclined sides. By screwing down the nut at the middle of the clamp, the shaft is held firmly while the keyway is being milled at the side.

HOLDING WORK IN VISE

34. Purpose of Vise.—The vise used in milling-machine work is intended for holding small work having two parallel surfaces, and can be used otherwise only by substituting special jaws for the regular ones. Milling-machine vises are made in various ways. When the machine is used only for plain milling, the vise is usually so made that it can be placed on the machine with its jaws either in line with or at right angles to the direction of motion of the table, but at no other angle. Such a vise is called a *plain vise*, and is most frequently used with plain milling machines.

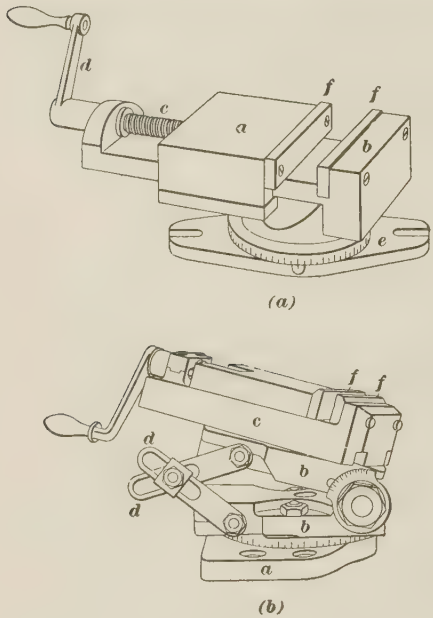

FIG. 7

35. Swivel Vise. For general work, the milling-machine vise is usually constructed with a swivel base, and is then called a swivel vise. One design of swivel vise is shown in Fig. 7 (*a*). It has a movable jaw *a* and a fixed jaw *b*, and the movable jaw can be set up by the screw *c* and the handle *d*. The base is circular, graduated in degrees, and can be swiveled around on the subbase *e* and clamped to it in any position. The subbase is bolted to the milling-machine table, and usually has a tongue that fits a T slot of the table and insures that a zero mark on the subbase is in line with one, and at right angles to the other, direction of motion of the table. The graduation on the base of the vise, as a general rule, is so placed that when its zero

coincides with the zero mark of the subbase, the jaws will be parallel with the arbor in the spindle. Consequently, the reading of the graduation indicates the angle included between the vise jaws and the axis of the spindle.

36. The vertical surface of the jaws in a regular milling-machine vise is always exactly at right angles to the surface of the table; consequently, if any work is held between the jaws, its top surface will be milled square with the sides in contact with the vise jaws. The vise is used as in planer work, and the same appliances and methods are employed for lining up the work and holding it fairly against the fixed jaw. However, the pressure of the cutting operation is much greater in milling-machine work; for this reason, the vise must be clamped very solidly to the table, and in case a cut is taken parallel to the vise jaws, the work must be held tightly enough to prevent slipping.

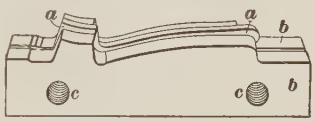

FIG. 8

37. Universal Vise.—The swivel vise shown in Fig. 7 (*a*) can be swung only in a horizontal plane; but in (*b*) is shown a universal vise, which can be swung either vertically or horizontally. It consists of three parts, which are the base *a*, the knee *b*, and the vise *c*. The knee is made in two parts, which are hinged together; the lower part is graduated, can swivel on the base, and can be clamped to it. The vise itself swivels on the upper part of the knee, which can be opened sufficiently to bring the vise vertical, and can be securely braced in any position by bracing levers *d* that are joined by a clamp bolt. The vise can be swung to any vertical or horizontal position, and consequently its range of usefulness is greatly extended over that of the swivel vise.

38. False Jaws.—All milling-machine vise jaws are faced with removable steel false jaws, as *f*, Fig. 7, which makes it an easy matter to substitute special jaws to hold special forms of work. Fig. 8 shows a pair of special jaws with the work *a* between them and indicates one of the forms in which

such jaws may be made. The false jaws *b* are fastened to the jaws of the vise by fillister-headed screws that fit the tapped holes *c*. These special jaws not only serve to hold work of a special form, but also support it close to the cut. Thus, the top of the false jaws should be made to conform to the profile of the work, but clearing it slightly. The rigid support of the work prevents springing and allows a wide cut to be taken with very little, if any, chattering.

39. Setting Vise on Horizontal Milling Machine. There are three different positions in which the vise jaws may have to be set on a horizontal milling machine, namely, square with the table, parallel to the table, and at an angle to the

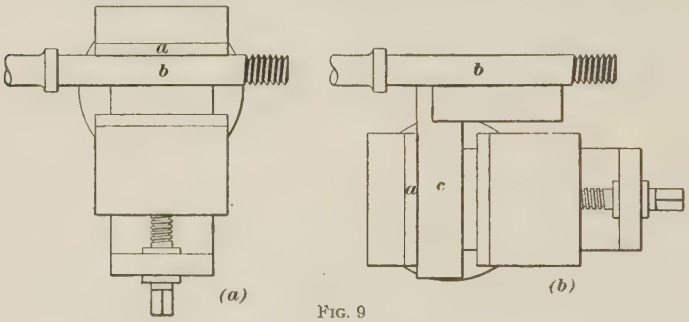

FIG. 9

table. As the arbor is at right angles to the table, setting the jaws square with the table means simply setting them parallel to the arbor, as shown in Fig. 9 (*a*). The vise is adjusted until the whole length of face of the fixed jaw *a* touches the arbor *b* held in the spindle. Another method is to place the beam of a square against the face of the column of the machine and then to adjust the vise until its fixed jaw is parallel to the blade. The jaws are set parallel to the table, that is, at right angles to the arbor, by the use of a try square, as shown in (*b*). The beam is held against the arbor *b* and the fixed jaw *a* is brought parallel to the blade *c*. The jaws are set at an angle to the table by placing the beam of a bevel against the face of the column or against the arbor, and then adjusting the fixed jaw until it is parallel to the blade.

40. Plain milling-machine vises usually have two slots at right angles to each other cut in the bottom. A tongue that fits a T slot of the table is fastened in one or the other of these slots and insures that the vise jaws are square with, or else parallel to, the table. In plain horizontal machines in which the table cannot be swiveled, and also in universal machines *when the table is set at zero*, the tongue insures that the vise jaws are either at right angles or parallel to the axis of the spindle, depending on the position of the vise. The swivel vise may be graduated with the zero directly above the tongue that locates the vise in the T slot and with the graduations extending to 90° at the front; or it may have the zero at the front and the 90° marks at each side, over the tongue. The position of the zero must be noted, and the settings made accordingly.

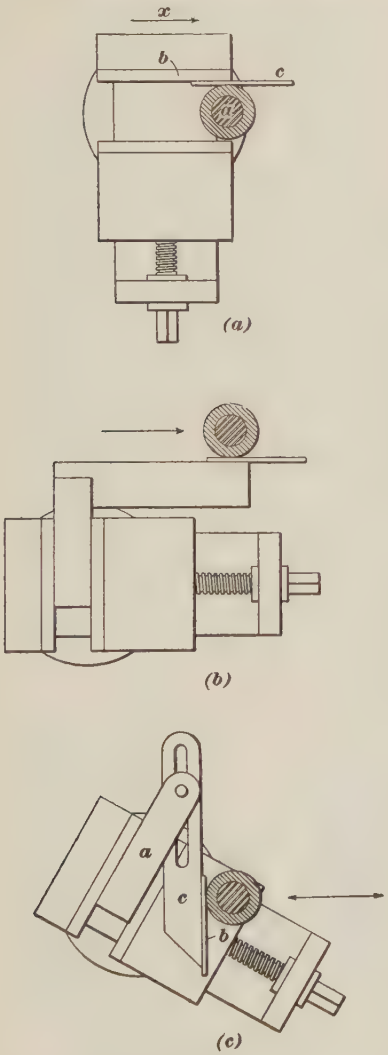

FIG. 10

41. Setting Vise on Vertical Milling Machine.—The arbor in the spindle of a vertical milling machine is vertical. A swivel vise without a graduation, or a graduated vise to be tested for the correction of its zero mark, may be set with

its jaws parallel to the line of motion or the length of a vertical milling-machine table as follows: An arbor is placed in the spindle, and the table moved with the lengthwise feed until the arbor *a*, Fig. 10 (*a*), is near one end of the fixed jaw *b*. Between the arbor and the vise jaw is set a parallel strip of metal *c*, and the vise moved toward the arbor until the feeling piece *e* just touches the arbor and the fixed jaw. The feeling piece is then removed, and the table moved in the direction of its line of motion, as shown by the arrow *x*, until the arbor is near the opposite end of the fixed jaw. The feeling piece is again inserted, to ascertain whether it comes in contact with the fixed jaw and arbor. If not, or if the feeling piece will not go in, the vise must be shifted and the testing repeated until the feeler is held the same at both ends.

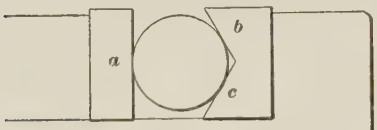

FIG. 11

42. To set the vise jaws square to the line of motion, a try square is clamped between the jaws and tested along the blade, as shown in (*b*). The vise is adjusted until the feeler shows the distance between the arbor and the square blade to be the same at both ends. To set the vise to an angle when the base is not graduated, instead of the try square use a bevel gauge *a*, as shown in (*c*), set to the correct angle by a protractor. Either the crosswise or the lengthwise feed, as required, is employed, and the vise is adjusted so that the feeler *b* is held the same at both ends of the blade *c*.

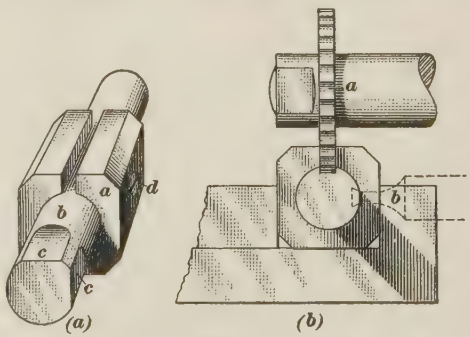

FIG. 12

43. Holding Round Work.—The regular milling-machine vise is not well adapted for holding round work, as

the jaws are in contact with such work only along one line. Hence, if the vise is tightened on the work, the jaws will mar it along the lines of contact. If the vise is used for holding round work, the marring may be lessened, and, at the same time, the work may be held more firmly, by placing strips of soft sheet copper or of sheet brass between the jaws and the work.

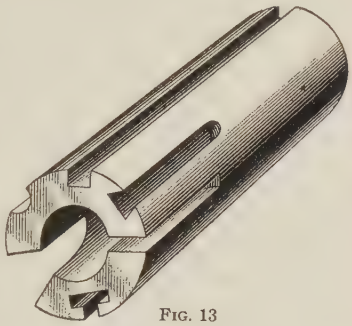

FIG. 13

44. False V Jaw.—When much round work is to be held in the vise, it will be found advisable to make a V-shaped false jaw, as shown in Fig. 11, which will cause the work to be held at three points, as *a*, *b*, and *c*, and prevent it from tipping upwards or downwards when a cut is taken over its top surface. Strips of sheet brass may be placed between the jaws and the work to prevent the latter from being marred.

45. Split Vise Chuck.—When a large quantity of round work of the same diameter is to be milled, the split vise chuck shown at *a*, Fig. 12 (*a*), may be used to advantage. It is made from a piece of steel or cast iron planed or milled square and true with the hole reamed through it, and the hole has the size of the work to be milled in it. The work *b* is slipped into the chuck, which is placed in the vise as shown in (*b*), and rapped down tightly on the bottom between the jaws. The vise is then tightened, gripping the piece firmly. A plain cutter *a* may then be passed through the slot to cut a keyway, or the work may be allowed to extend beyond the end of the chuck and an angular cutter *b* may be used to cut a dovetailed slot.

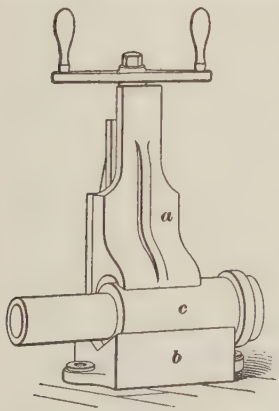

FIG. 14

The flat surfaces act as an index for milling squares or flats on work as shown at *c* in view (*a*). In this case, the work is held from turning in the split chuck by tightening the setscrew *d* in the side of the chuck. Fig. 13 shows several examples of the kinds of work that may be done on a cylindrical piece held in a split chuck vise.

46. Special Vise.—The plain milling machine is often used entirely for making simple cuts on cylindrical work; in such a case, a special vise may be employed, like the one shown in Fig. 14. The movable jaw *a* is flat in this vise, which may be made vertical, as shown, when the character of the work makes it a more convenient design. The fixed jaw *b* is V-shaped, so that the work *c* will be lined up and firmly held. The resemblance of the vise jaws to the special jaws shown in Fig. 11 should be noted.

HOLDING WORK BETWEEN INDEX CENTERS

47. Types of Index Centers.—To suit different classes of work, two types of index centers are made, known as *plain index centers* and *universal index centers*. Each type has a live spindle that can be rotated at will through a definite

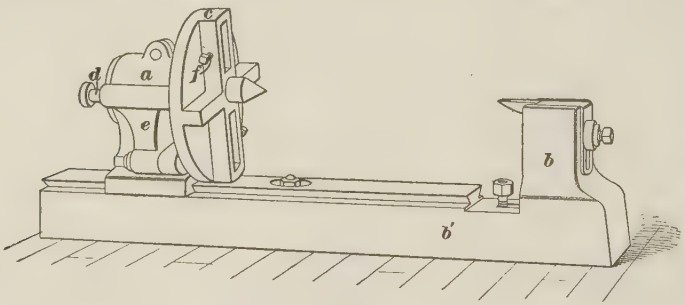

Fig. 15

part of a revolution and a tailstock carrying the dead center. The distance between the two centers is adjustable to accommodate different lengths of work.

48. Plain Index Centers.—One design of a set of plain index centers is shown in Fig. 15. The index head *a* is adjust-

able along the base, and the tailstock *b* forms part of the bedplate *b'*. In many designs, however, the index head and tailstock are not placed on a bed, but are clamped directly to the table of the milling machine; in that case, each usually has a tongue on the bottom that fits a T slot of the table and insures the proper alinement of the index centers. The headstock *a* carries the live spindle on which an index plate *c* is secured.

49. The back of the index plate, Fig. 15, has several concentric rows of holes, which are spaced equidistantly in each separate row. An index pin *d* is inserted in a movable bracket *e* in such a manner that its pin end may be made to engage with any row of holes. The holes in the index plate are used for obtaining divisions of the circle, that is, to indicate when the spindle has been revolved a given number of degrees. The divisions obtainable depend on the numbers of holes in the different rows; they are the quotients obtained by dividing the number of holes in each row by all the whole numbers by which it is divisible. In each case, the quotient shows how many holes the index plate must be moved for each division.

50. The spindle is placed in line with the dead center, Fig. 15, and cannot be swiveled vertically. It carries a live center and a face plate that takes the tail of the dog used for confining the work, and a setscrew *f* holds the tail of the dog. The dead center has a limited range of adjustment in line with the axis to allow work to be placed and removed from between the centers without having to move the index head. Some designs of the plain index head allow a universal lathe chuck to be screwed to the live spindle, thus greatly increasing the range of usefulness. In practically all designs the live center may be removed, and an arbor or a collet may then be inserted for holding the work.

51. Universal Index Head.—The universal index head shown in Fig. 16 differs from the plain index head, in that the index-head spindle can be swung vertically, from 10° below the horizontal to the vertical position and 50° back

of the vertical. In the design shown, the head *a*, which carries the spindle, is mounted in a circular guide on the frame *b*, and may be rigidly clamped to it in any position within its range of movement. The head *a* is graduated in degrees, and a zero mark placed on the frame indicates, by its coincidence with a graduation mark, how many degrees the axis of the spindle is swung from its horizontal position. The tailstock *f* is bolted to the table, and is made movable to accommodate different lengths of work.

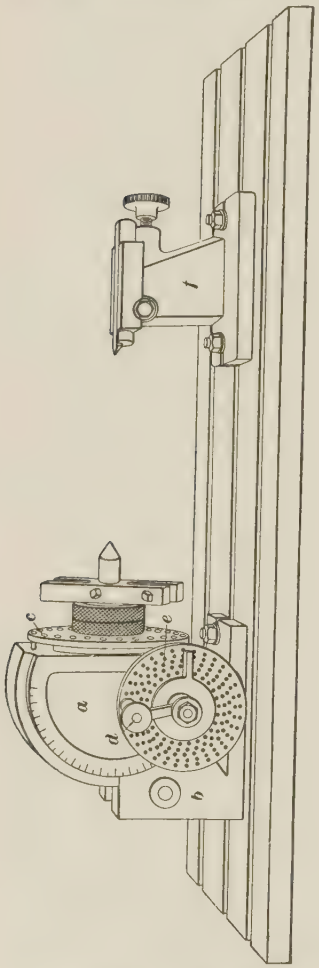

FIG. 16

52. In the design shown in Fig. 16, the spindle carries an index plate *c* with a circle of holes in it, which may be used for rapid indexing for the most commonly used divisions of the circle. A worm-gear, which is inside the head, is keyed to the live spindle and a worm, keyed to a shaft, meshes with this wheel. The shaft carries an index crank through which the pin *d* passes, and the latter can be made to engage with any of the concentric rows of holes of the index plate *e*, which is fastened to the head. The spindle is rotated by turning the worm-shaft by use of the index crank after the pin is withdrawn from the plate. For direct indexing with the plate *c*, the worm is disengaged from the worm-gear, after which the movement can be made very quickly.

53. Universal index heads are often constructed in such a manner that the feed-screw of the table and the worm-shaft may be connected by gearing. The spindle of the index head will then revolve when the table moves in a straight line. The work that is most commonly done between centers is the fluting of drills, taps and reamers, the milling of the spaces of milling cutters, the cutting of small gear-wheels and sprocket wheels, the milling of squares on the ends of cylindrical tools, the cutting of short keyways, and similar work.

54. Driving of Work.—Work held between the centers is caused to rotate with the spindle by a dog. To prevent any rocking of the work the tail of the dog must be confined by a setscrew, which is always tapped into the face plate or

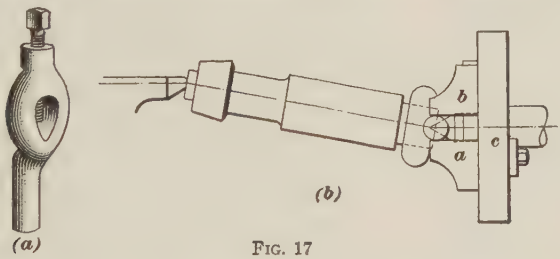

FIG. 17

driver. Ordinary lathe dogs are not particularly well adapted for milling-machine work, as their tails will rarely come opposite the setscrew in the driver. A regular clamp dog with a flat tail will be found more satisfactory in all respects than the lathe dog, as it will allow the tail to be brought opposite the setscrew on all kinds of work within its range.

55. Milling-Machine Dog.—The tail of the ordinary dog will cramp badly when driving taper work with the centers set out of line. The dog shown in Fig. 17 (*a*) will not cramp, but it requires a pair of driving jaws attached to the driver or face plate. The dog has an offset cylindrical tail that is placed between the special jaws *a* and *b*, as shown in (*b*). The jaw *a* is bolted to the face plate *c* and carries a small slide to which the movable jaw *b* is clamped. In use, the

dog is so placed on the work that the axis of the tail is about flush with the end of the work. The tail is now in contact with the fixed jaw *a*, and the movable jaw *b* is pushed against it and locked. Owing to the construction, the dog can move freely back and forth between *a* and *b*, and also rock as required during the revolution of the work, and there is no cramping or bending of the work. This dog produces less error in dividing work than the bent-tail dog, but it will not allow even divisions to be made while the centers are out of line.

56. Lining Universal Centers to Same Height. The universal milling-machine centers require lining up when a cut is to be taken parallel to the axis of the work. There are two cases that may arise in practice, in which a slightly different method of procedure is necessary to line the centers up to the same height. When the tailstock is so arranged that the dead center is movable vertically, the index head is set to zero as accurately as possible, and a true-running milling-machine arbor is placed in the index-head spindle. Practically all modern milling machines have the same taper in the main spindle and the index-head spindle; consequently, the arbor intended for cutters may be used. The pointer *p* of a surface gauge is adjusted just to touch the top of the arbor near the shoulder, as shown in Fig. 18. The surface gauge is shifted to the end of the arbor; if the pointer just touches the top again, the index-head spindle is set parallel to the surface of the table. If the arbor shows the head to be too high or too low, it must be adjusted and the tests repeated until they show the same at both ends, when the head will be correctly set. The alinement of the dead center is then

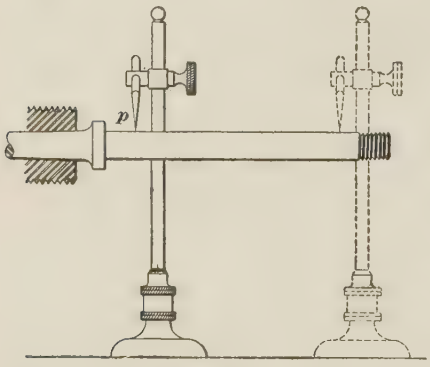

FIG. 18

tested by clamping it near the arbor and running the center into the cleaned center hole in the end of the arbor. If the outer end of the arbor is shown to be raised or lowered when tested by the surface gauge, the dead center is adjusted up or down and another test made. This process is repeated until, when the dead center is tightened in the center hole, the surface-gauge pointer will touch the arbor with the same pressure at each end.

57. When the tailstock center is not movable vertically, as in the case of the tailstocks shown in Figs. 15 and 16, the index head is set as closely as possible by the zero mark on the frame and the zero of graduation on the head. A piece of stock is then placed between the centers, as *a* in Fig. 19, one end of which has been turned to run true, with the turned end toward the tailstock. The pointer of a surface gauge is now so adjusted as just to touch a strip of paper *p* placed on top of the turned end. The piece *a* is next turned end for end, and in a similar way the height at the live center is tested. If it shows that the spindle is too high or too low, the head is adjusted so that the pointer will touch the feeling strip properly. The tests are repeated until the feeler *p* is held with the same pressure at each end.

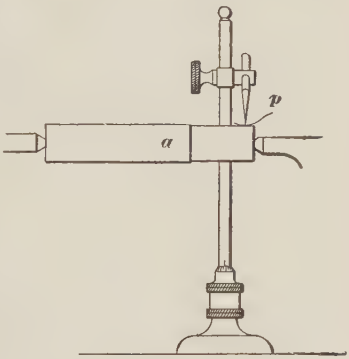

FIG. 19

HOLDING TAPER WORK BETWEEN CENTERS

58. When cuts are to be taken at an inclination to the axis of work held between milling-machine centers, that is, when tapering work is to be milled, the work may be set to the required inclination in various ways, depending on the construction of the centers available.

The cases that may arise in practice are as follows: (*a*) Neither the index-head spindle nor the tailstock may be

adjustable in a vertical plane, as is the case with the plain centers shown in Fig. 15; (*b*) the tailstock may be adjustable in a vertical plane; (*c*) the index-head spindle may be swung in a vertical plane; (*d*) the index-head spindle may be swung in a vertical plane and the tailstock be adjustable vertically in the same plane; (*e*) the index-head spindle and the tailstock may be swung in a vertical plane around the center of rotation of the index head.

59. Non-Adjustable Index Head and Tailstock.—In the case (*a*), there are two ways in which tapers may be milled, depending on the kind of machine and milling cutter available. By using a horizontal machine and a plain cutter, the axis of the work *a*, Fig. 20 (*a*), may be brought to the required inclination to the line of motion *x y*, by packing up under one end of the bed *b'*, Fig. 15. The true alinement of the centers is thus preserved; that is, the axis of the index-head spindle coincides with the axis of the dead center, irrespective of the inclination of the axis of the index-head spindle to the line of motion. When this is the case, the work will always revolve in perfect unison with the spindle; that is, the angular movements of the spindle and work will always be alike, in consequence of which, it is possible to divide tapering work into even divisions. There is no axial movement of the tail of the dog during the revolution of the work, and there is no cramping and springing.

60. When plain centers are used for a vertical milling machine and an end milling cutter is employed, the adjustment is identical with the one just described. When a plain cutter is to be used in a vertical milling machine, or an end mill in a horizontal machine, the centers must be shifted sidewise; that is, they must be moved in a horizontal plane until the horizontal angle between the axis of the work and the line of motion of the table is equal to the desired angle. When the bed of the centers has tongues fitting a **T** slot of the table, parallel bars must be interposed between the table and the bottom of the bed.

61. Raising Tailstock.—Case (*b*) usually occurs with plain centers that are fastened directly to the table, and when using a plain cutter in a horizontal milling machine, or an

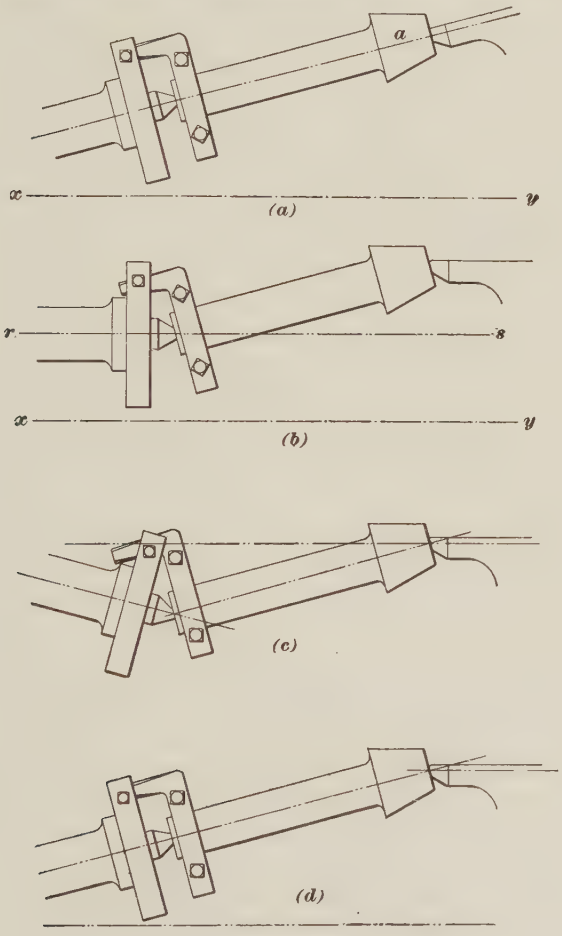

FIG. 20

end mill in a vertical machine. The axis of the work is then often given the required inclination by blocking up either the index head or the tailstock with suitable packing blocks. The position of the centers in that case is shown in Fig. 20 (*b*).

In packing up with parallel packing blocks, the axis of rotation $r\ s$ of the spindle remains parallel to the line of motion $x\ y$ of the table, but the axis of the work and spindle are at an inclination to each other. This condition is equivalent to that existing in lathe work when taper turning is done with the tailstock center set over, and the same trouble is experienced as in lathe work; that is, the angular movements of the spindle and work are not equal.

62. In other words, with the centers out of line, it is not possible to obtain even divisions of the work with even indexing. The trouble is intensified by the fact that the tail of the dog in milling-machine work must be confined with a setscrew. If the different positions of the tail during one revolution of the work are observed carefully, it will be seen that it not only slips to and fro in the slot of the driver, but that it has a rocking motion at the same time. If the spindle is revolved while the setscrew is set against the tail, the latter will be cramped, and either must bend or the work must spring. For this reason, whenever work held between centers that are not in line with each other is revolved, the setscrew should be loosened before revolving the index-head spindle and tightened again on the completion of the movement. While this will prevent springing of the work, it will not give even divisions.

63. When plain centers or universal centers intended to be fastened directly to the table are to be used in a horizontal machine for taper work where the cutting is to be done by an end mill or by a plain mill in a vertical machine, the centers must be shifted horizontally until the line joining them makes the required horizontal angle to the line of motion of the table. For this purpose, raising blocks, if available, may be used; in the absence of such blocks, the centers may be blocked up on parallels. To obtain even divisions, the tailstock center must be so placed that it coincides with the axis of the index-head spindle. Instead of fastening the centers separately to the table, it will be found much better to have them attached to a temporary bed, which insures their always being in line, and swivel the bed upon the table.

64. Adjustable Index Head.—Case (*c*) occurs with some designs of universal index centers, where the tailstock is not adjustable vertically, and when the work is done with a plain cutter in a horizontal machine, or an end mill in a vertical machine. The index head is then raised or depressed to suit the taper. This method still further increases the unequal spacing and cramping of the dog. Comparing equal tapers, case (*c*) will give errors slightly more than double those due to case (*b*).

65. Whenever possible, the work should be so placed between the centers that the index-head spindle is raised above a horizontal plane; the tailstock can then usually be blocked up by packing blocks or parallels until the axis of rotation of the index-head spindle coincides with the dead center, as shown in Fig. 20 (*d*). When this is done, even divisions will be obtained and there is no cramping of the dog or springing of the work. The only objection to the use of a parallel packing block, or parallels, for raising the tailstock is that the dead center will not have a fair bearing in the countersink of the work. When conditions permit, a tapering packing block may be made to overcome this trouble.

66. Adjustable Index Head and Tailstock.—When the tailstock center is adjustable in a vertical plane independently of the live center, which is case (*d*), the tailstock center may be raised until it coincides with the axis of rotation of the spindle. Even divisions may then be obtained.

67. Taper Attachment.—Case (*e*) involves a special construction of the index centers. In the device shown in Fig. 21, the live center *a*, which fits the tapering hole of the index-head spindle, has a large cylindrical collar in front that closely fits a bored hole in an arm of the bed *b*. The tailstock *c* is so mounted on this bed that it can be moved along to accommodate different lengths of work. The construction of the bed insures that the dead center is always in line with the axis of rotation of the live center. In use, the live center is driven home in the index-head spindle. The index head is then raised until the required inclination has been reached

and the free end of the bed, which swings with the index head, is tied to the table by clamping it to the bracket *d*. This bracket has previously been bolted to the table. The device insures that the axis of rotation of the live center always coincides with the dead center, and, consequently, even divisions may be obtained.

68. Setting Centers for Equal Divisions on Tapered Work.—In milling taper work between centers, when equal divisions are to be obtained, *the axis of rotation of the spindle and the axis of rotation of the work must coincide.* When this condition is not attainable, it is impossible to obtain even divisions. When the angle of inclination is small, the errors

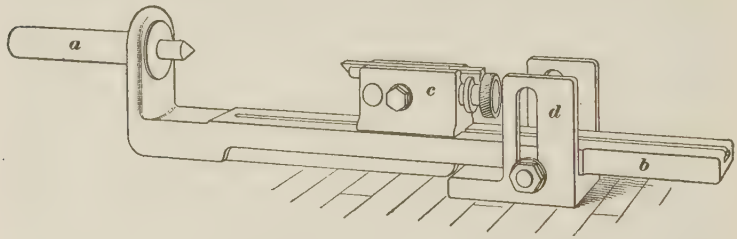

FIG. 21

of division will be very small; they will rapidly increase, however, for any increase of the inclination.

69. It is to be noted that with a constant difference of elevation between the centers, the angle of inclination of the axis of the work to the line of motion of the table in cases (*b*), (*c*), and (*d*) will vary for different lengths of work, and hence the tailstock center must be moved up or down for different lengths of work if the angle of inclination is to be kept constant. In cases where the two centers are attached to a separate bed that preserves their alinement, and where the bed is then inclined or swiveled, as in case (*a*) or (*e*), for instance, the angle of inclination to the line of motion is not affected by the distance between the centers, that is, by the length of the work. In case (*c*), it is to be further noted that no attention must be paid to the graduation marks of the index head; they do not show the angle of inclination between the

axis of the work and the line of motion of the table. In case (*d*), however, the graduations will correctly indicate the angle of inclination, but only when the tailstock center has been raised enough to make the axes of rotation of the index-head spindle and work coincide. As far as case (*e*) is concerned, the construction insures that the graduation marks correctly indicate the inclination.

70. Lining Index Centers for Taper Work.—As previously stated, when equal divisions are to be produced on work done between centers, it is absolutely necessary that the index centers be in line; that is, the axes of rotation of the work and of the index-head spindle must coincide. The shifting of the centers to bring them into alinement naturally depends on their construction and the conditions of each case, and no general directions that could be given would be of the same value as the exercise of a little judgment. Their correct alinement may be tested in various ways; one of the simplest and most accurate methods is here given, which has the advantage that it requires no special tools, is rapid, and needs no especial skill.

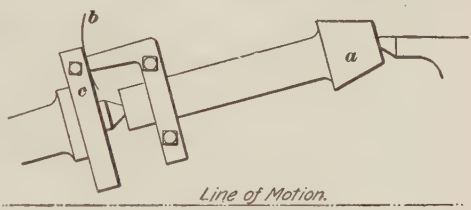

FIG. 22

71. The work *a*, Fig. 22, is placed between the centers with a clamp dog mounted on it and revolved until the tail of the dog is on top and in the vertical plane passing through the axis of the work. The dog is now adjusted until the end of the tail will just touch a feeling piece *b* placed between it and the driver *c*. This feeling piece may be a strip of tin, paper, brass, etc. The feeling piece is removed, and the index-head spindle given one-half turn, thus bringing the spot on the driver that was opposite the end of the tail to the bottom. The work is next revolved one-half revolution; if the feeling piece will not go between the driver and the dog, the tailstock center is too low; if it enters freer than it did

in the first position, the tailstock center is too high; and if it just goes in with the same degree of tightness that it did in the first position, the centers are in line in a vertical direction. To test their alinement sidewise, the driver and the dog are placed in their two horizontal positions and the feeling piece applied in each position. If for any reason the work itself cannot be used, a mandrel of the same length, and with centers of the same size as in the work, may be employed instead.

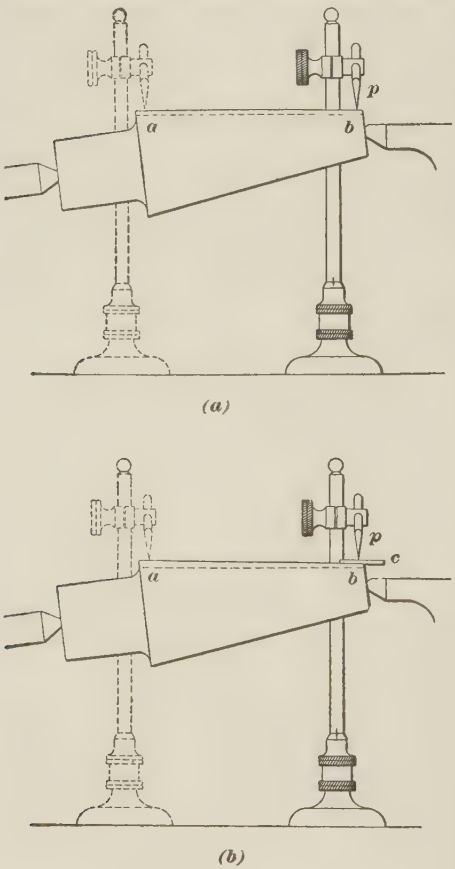

FIG. 23

72. Setting Taper Work.—The cases that arise in practice in milling taper work between centers require the cut to be taken either parallel to the surface of the work or at an inclination to it. When setting the centers so that the cut, the depth of which is represented by the dotted line *a b* in Fig. 23 (*a*), will be parallel to the surface of the work, a surface gauge may be employed for testing when using a horizontal milling machine and a plain cutter, or a vertical milling machine and an end mill.

73. The work having been placed between the centers, these are adjusted by eye until the top of the work appears

about parallel to the surface of the milling-machine table. The pointer *p*, Fig. 23 (*a*), of a surface gauge is then adjusted to just touch the work at one end; the gauge is now shifted to the other end, to the position shown in dotted lines, and it is noted whether the pointer is again in contact with the work. If it does not touch, the work must be raised at the left end, or the right end must be depressed. After shifting, the testing is repeated until the surface gauge pointer touches the same at both ends.

74. When the cut is to be deeper on one end than at the other, as indicated by the dotted line *a b* in Fig. 23 (*b*), the setting may be tested by a surface gauge and a test piece *c*. This test piece should be a very narrow strip of metal whose height is made equal to the difference in the depth of the cut at the two ends. Place the block on top of the work, holding it parallel to the table and set the pointer *p* of a surface gauge to touch it. Then shift the surface gauge to the other end and note whether the pointer touches the work. If it does touch, the work is correctly set; otherwise, it must be adjusted until it touches the same at both ends. When using a plain cutter in a vertical machine, or an end mill in a horizontal machine, a pointer may be clamped to the spindle, or one of the cutting edges of the cutter itself may be used for testing the setting, traversing the work past the selected testing point by moving the table.

75. On some classes of work, as, for instance, the blank for a bevel gear mounted on an arbor between centers, the angle that the cut makes with the axis of the work is given. With a universal head, raise the index head until the graduations indicate the given angle; now place the work between the centers and raise the tailstock until it is in line, testing by means of the method described in Art. **71.** When a special attachment like that shown in Fig. 21 is used, the testing is superfluous; all that is required is to set the index head to the given angle.

76. Setting Index Centers Sidewise.—When the centers are to be set sidewise to a given angle, as occurs when

using them in a horizontal machine with an end mill, or a vertical machine with a plain mill, there are usually no graduations available by which to set the centers. Various expedients may then be adopted. For instance, a piece of tin, as *a*, Fig. 24 (*a*), may be so cut that the angle *b* equals the given angle, and placed against a cylindrical mandrel held between the centers, which are now shifted until traversing the table

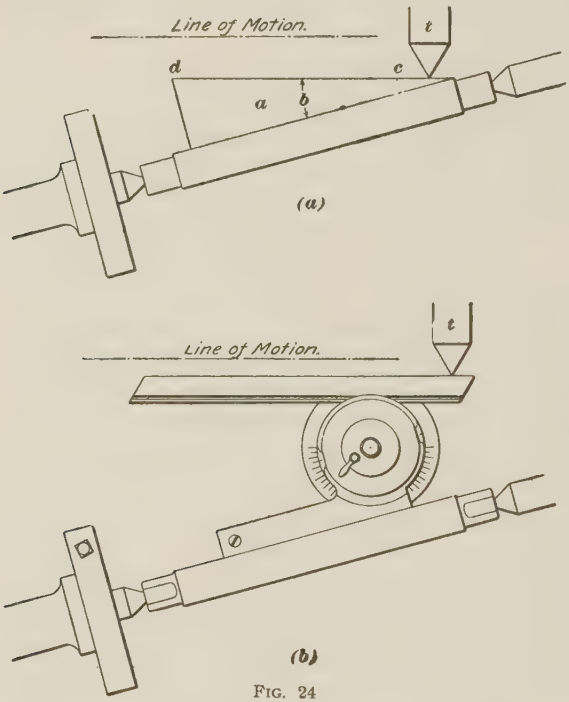

FIG. 24

past the stationary testing point *t* shows the test side *c d* of the triangle *a* to be parallel to the line of motion of the table. The testing point may be a piece of wire clamped to the spindle.

77. When a universal bevel protractor of the type shown in Fig. 24 (*b*) is available, it may be set to the required angle and placed against a cylindrical mandrel held between the

centers. Their setting may then be tested by traversing the table and the blade of the bevel protractor past a stationary testing point *t*, and adjusting until the pointer touches the whole length. When the two centers are mounted upon a bed, this bed will usually have a straight side that is parallel to the centers. In that case the bevel protractor or the tin triangle may be applied to that surface, instead of to the mandrel, observing the necessary precaution of holding the instrument used parallel to the surface of the milling-machine table.

MILLING-MACHINE WORK
(PART 3)

OPERATION OF MILLING MACHINE

HOLDING AND STEADYING WORK

HOLDING WORK IN CHUCK

1. Milling-Machine Chuck.—As a general rule, the chuck used in milling-machine work is a self-centering lathe chuck that is fitted to a face plate screwed to the index-head spindle. For holding small cylindrical work and tools a high-grade self-centering drill chuck may be fitted to a shank that fits the hole of the index-head spindle. Regular independent-jaw lathe chucks may be used on the index-head spindle; these chucks have the advantage that work held in them can be set so that it runs perfectly true. It is rarely advisable, however, to fit an independent-jaw chuck to the index head unless the milling-machine spindle is threaded the same as the index-head spindle; the chuck can then be screwed to the milling-machine spindle and the work there trued up as easily as in the lathe, as it rotates at a high speed. After truing, the chuck is transferred to the index head. It is a very tedious job to set work true in a chuck while on the index-head spindle, except in machines provided with means for disengaging the worm and the worm-wheel.

2. Self-centering chucks, if of a high grade and carefully fitted, can be relied on to hold work within their capacity very

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true; they will also stay true for a long time if used with reasonable care. But even though made with the greatest of care, they will rarely hold work so that it runs perfectly true, and in spite of careful use they will soon wear further out of true. It is therefore not advisable to use a self-centering lathe chuck for work that requires cuts to be very true in respect to its axis; when this is considered necessary, the work should be trued up in some other manner, as, for instance, by driving or clamping it on a true-running arbor held on centers or driven into the index spindle. The self-centering chuck, however, has the advantage of being rapid in gripping and releasing work, so it is generally used.

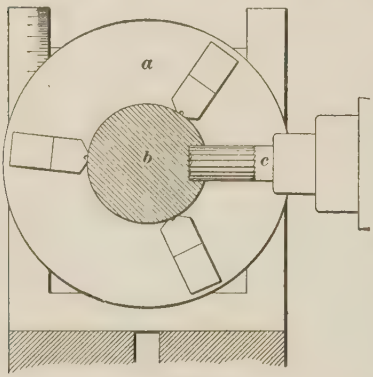


FIG. 1

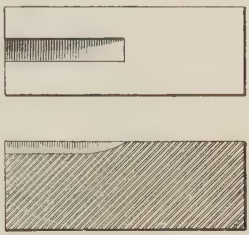
3. Examples of Chuck Work.—A great variety of work can advantageously be done with the piece held in a chuck, among which may be mentioned the milling of squares on the ends of taps and reamers, the cutting of lengthwise grooves on work too long to go between the centers but small enough to pass through the index-head spindle, milling out the spaces of spring dies and hollow mills, and similar work. A few examples are here given, which will act as suggestions as to the class of work and the kind of cuts for which the chuck is adapted.

4. Grooving or Key-Seating Work.—Fig. 1 is a front view, looking lengthwise, of the table of an index head, with a three-jawed chuck *a* in which the work *b* is held. A straight rectangular groove is to be milled in the work for a part of its length. When the groove is to have a round end, as shown in Fig. 2 (*a*), an end mill *c* should be used, as shown in Fig. 1. When the groove is to begin and end in solid metal, a hole the size and depth of the groove is drilled at the starting point. An end mill of the required diameter is driven into the spindle

and the work is raised so that its axis is at the same height as the axis of the cutter. The hole in the work is then set to match the cutter and the cutter is fed in after setting the table stop to locate the starting end. The groove is then cut to the required length and depth by taking one or more cuts.

(*a*)

5. When the inner end of a keyway must be straight, as in Fig. 2 (*b*), a plain cutter is placed on the arbor and is set central over the work, as shown in Fig. 3. The work is then raised so that the cutter will cut to a depth of half its width, and is fed the required distance. No drilling is necessary, though it is sometimes done at the end of the keyway if the curved corner, as shown in Fig. 2 (*b*) at the bottom of the inner end of the cut, has to be made square by chipping. In such a case, the drilled hole lessens the amount to be chipped out.



(*b*)

FIG. 2

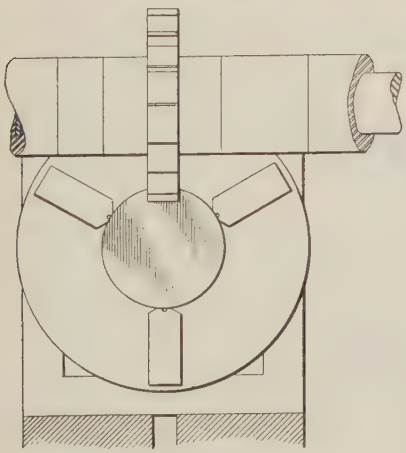


FIG. 3

6. Milling Polygons. When milling a square, or any other polygon, on the end of round work held in the chuck, the way in which the cut is to end will determine the kind of cutter to be used and the direction of the feed. For instance, when a horizontal machine and a plain cutter are used, and the feed is in the direction of table travel, as indicated by the arrow *x* in Fig. 4 (*a*), the cut will end in a curved shoulder having a curvature equal to that of the cutter. For some work, this may be a decided advantage, as, for instance, when milling a

punch, since this way of ending the cut will leave the punch very strong and greatly reduce its liability to crack in hardening: for other work, again, it may be a decided disadvantage. Thus, assume that the square at the end of a tap was cut in the manner illustrated in (*a*). Then, the tap wrench will jam on the curved shoulders and be difficult to remove. In this case, it is better to make each flat with a shoulder; this may be done by using an end mill or a side mill, feeding vertically, or in the direction of the arrow *x*, as shown in (*b*).

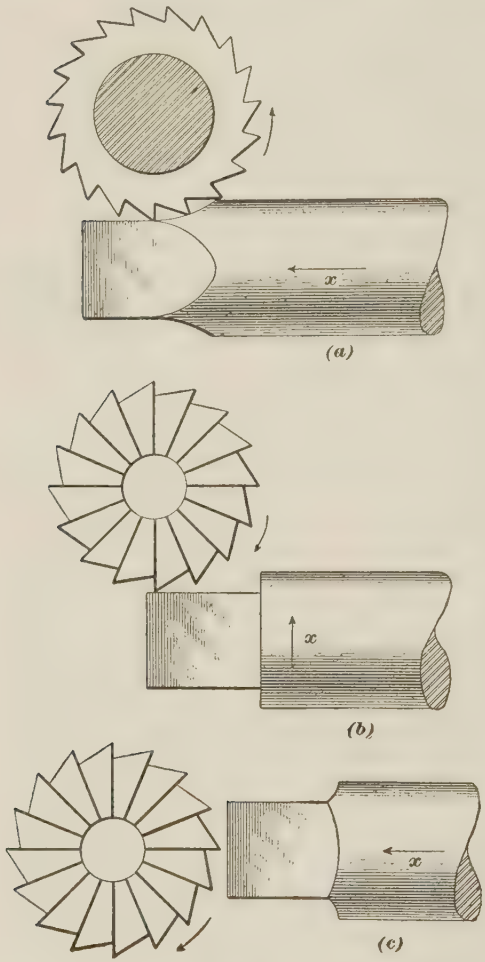


FIG. 4

7. A cut to end in a shoulder curved as shown in Fig. 4 (*c*), may be made with an end mill, a side mill, or a pair of side mills used as straddle mills, feeding in the direction of the arrow *x*. In this case, the axis of the work should be at the same height as the axis of the cutter. A square made as in (*c*) can be finished in less time than that required for the method shown in (*b*). The reason for this is that the distance traveled by the cutter is less in (*c*).

8. Circular Chuck Work.—A suggestion of what may be done in the way of circular milling is shown in Fig. 5, using in this case a horizontal machine and an end mill. The work is shown enlarged in (*a*). It is required to finish the curved surface *a*, and also the rest of the face, which may be done by holding the stem *b* of the work in the chuck and using an end mill, as shown in (*b*). For finishing the curved surface, the axes of rotation of the cutter and of the work should not intersect, but the axis of the cutter should be below the axis of the work a distance at least equal to the radius of the central hole in the end mill. When cutting the curved surface *a* of the work, the feeding is done by rotating the index-head spindle to the right in the direction of the arrow *x*. As soon as the cutter has passed clear over the curved surface, the knee of the milling machine is raised; the work is then rotated until the straight face *c* is vertical.

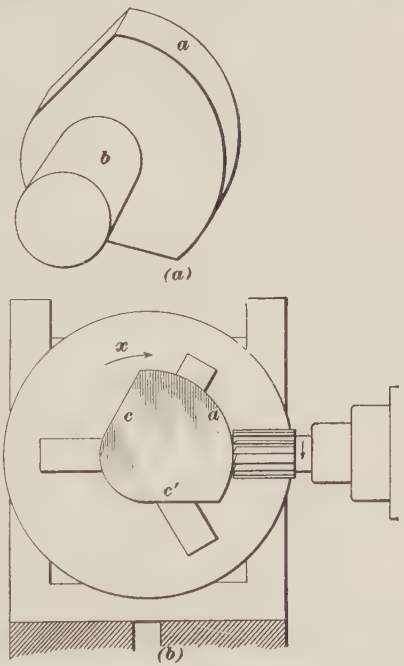


FIG. 5

9. By means of the cross-feed screw, the table is fed toward the cutter until the required depth of cut is reached; the feeding is then done by lowering the knee until the curved part of the work is reached. The index-head spindle is now slowly rotated in the direction of the arrow *x*, Fig. 5 (*b*), until the straight side *c′* comes vertical; the knee is then fed upwards until the cutter has passed over *c′*, which completes the milling of the work. The method just described for finishing the piece shown in (*a*) is not given as the only way or the best way

in which this job can be done, but merely to suggest to the operator the character of work that may be done in this manner.

10. Precautions in Using Chuck.—When cuts are to be taken at one side of the center on work held in the chuck, it should always be the aim to select the cutter or arrange the machine so that the pressure of the cut will not unscrew the chuck from the spindle. Suppose that a cut is taken as shown in Fig. 6 (*a*), and that the chuck is screwed on with a right-hand thread. Then, the pressure of the cut will tend to rotate the chuck in the direction of the arrow *x*, that is, left-handed, which will unscrew the chuck. For making the cut, the cutter should occupy the position shown in (*b*). The pressure of the cut will then tend to rotate the chuck to the right in the direction of the arrow *y*, and thus screw it home more firmly.

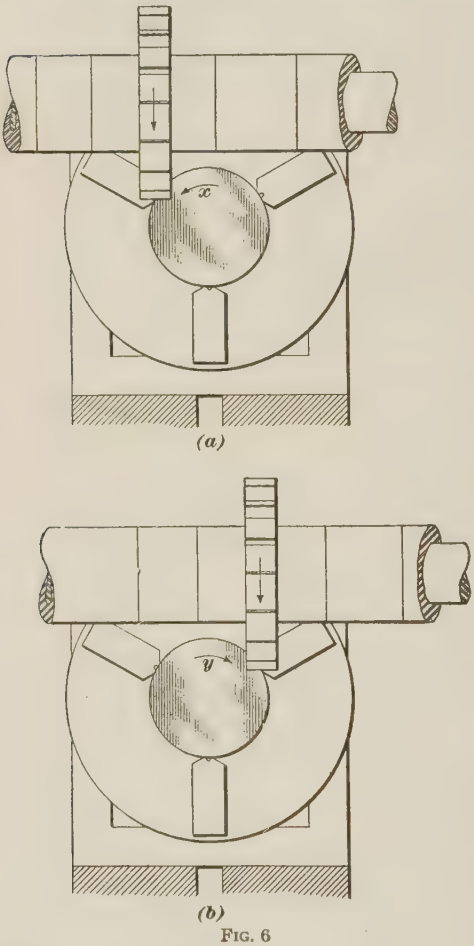


FIG. 6

11. The cutter cannot always be so selected nor the machine so arranged that the pressure of the cut will not tend to unscrew

the chuck. Making a hollow mill, shown in Fig. 7, is an example. Such a mill, as a general rule, cuts right-handed, the term *right-handed* being applied to this mill as it must turn to the right to cut. Hence, to form the cutting edges, the cut

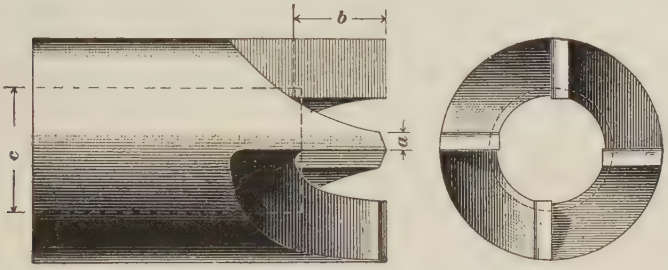


FIG. 7

must be taken to the left of the center, or as in Fig. 6 (*a*). Now, if the chuck is screwed on with a right-hand thread, there is a pronounced tendency to unscrew the chuck, on account of the width and depth of the cut. For this reason, special pains must be taken to jam the chuck firmly against the shoulder on the index-head spindle, when the thread is right-hand, and great care must also be exercised when taking the cut. The chuck may sometimes be blocked by putting a jack under one of the jaws, and this should be done whenever circumstances permit. When a chuck that is fitted to the index-head spindle by a shank is available, and is of sufficient size, it should be used in preference to a threaded chuck.

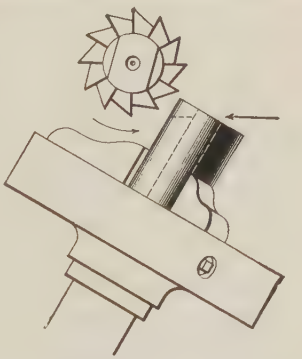


FIG. 8

12. Angular Cuts.—Cuts may be made at an angle to the axis of work held in the chuck by inclining the universal head, as shown in Fig. 8. A great variety of work can thus be done, as, for instance, milling the teeth on the ends of end mills, or the teeth on the sides of solid side mills, milling bevel gears, etc.

Some angular cuts can be made with the work held in the chuck, and others can be done more readily and accurately by using some other holding device, as an arbor.

13. Protection of Finished Surfaces.—The chuck jaws are prevented from marring finished work by bending a strip of soft copper, brass, sheet iron, or tin into a ring the size of the work and slipping the ring on the piece before it is gripped in the chuck. Work held in the chuck should project as little as possible to get the best bearing of the jaws on the work and to reduce its spring during the cutting operation.

ARBORS FOR INDEX-HEAD USE

14. Arbors to be used in the index head may be made in many different ways to suit the nature of the job. For holding saw blanks, face cutters, solid side cutters, and other similar cutting tools for the milling machine while milling the teeth in them, an arbor like the ordinary lathe mandrel or the cutter arbor may be used. On many jobs, such an arbor cannot be used, as it will interfere with the milling cutter; in such a case, some other form of arbor must be adopted. In designing a special arbor, the nature of the job will largely determine its shape. Usually the choice is limited to a few designs. Several designs are here given as suggestions of what may be done.

15. Expanding Arbors.—The arbor shown in Fig. 9 (*a*) is intended for holding work with a central hole so that it may be milled on the side, as for instance, a small side milling cutter or a bevel gear. The shank of the arbor is made to fit the tapered hole in the index-head spindle. A collar is formed on the arbor in such a position that when the arbor is in the spindle the collar will be about $\frac{1}{8}$ inch from the spindle. The collar locates the work and prevents it from moving toward the spindle. The front or work end of the arbor is finished to be a fair fit in the work and is split into three or more parts by slots terminating in holes close to the shoulder. A screw with a tapering head will expand the split end so as to hold the work, which is slipped on the arbor before the screw is tightened. The arbor

shown will hold the work central, and is inexpensive. Its disadvantages are that it can be used for only one size of hole, and that it will not hold the work so firmly as some other designs.

16. An arbor that will hold the work more firmly is shown in Fig. 9 (*b*). The end is split into three or more parts and is made to fit the hole of the work; a central hole is drilled through

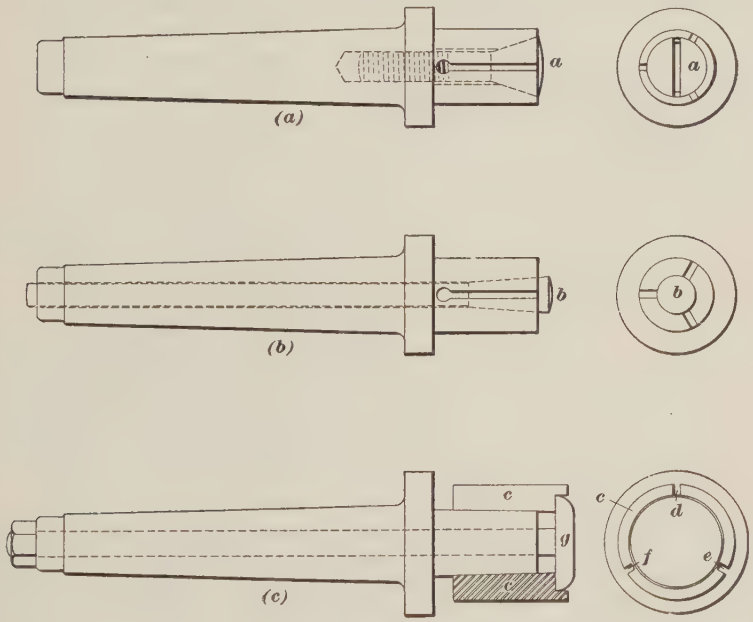


FIG. 9

the arbor and reamed tapering at the front end. A taper pin *b* is fitted to it, and is driven in to expand the arbor. To loosen the work, the pin is driven out, which may be done with a rod and a hammer. The rod may be dispensed with if the taper pin is made with a long, straight shank extending beyond the end of the index-head spindle, as is shown in the illustration. If the split end before expanding is a fair fit in the hole of the work, it will hold the latter central and also very firmly, as a greater pressure, and hence more friction can be created by

driving the taper pin home than can be obtained by tightening a conical-headed screw with a screwdriver. This design is perhaps slightly more expensive than the previous one, but it is to be preferred because it holds the work more firmly. It has the disadvantage of being adapted for but one size of hole.

17. Bushed Expanding Arbor.—A design that can easily be adapted to various sizes of holes at a comparatively slight expense is shown in Fig. 9 (*c*). Here the front end of the arbor is tapered slightly, so that the included angle is from 2° to 3°. A bushing *c* is bored to fit the tapered end of the arbor, and is turned outside to fit the hole of the work. It is split by an axial slot *d*, and to allow it to expand easily, several shallow slots, as *e* and *f*, may be cut around its cir-

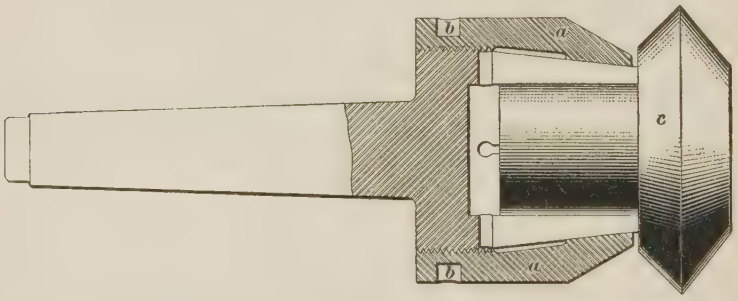


FIG. 10

cumference. The bushing may be expanded by a bolt *g* extending through the arbor and having a nut at the rear end, or it may be held by simply driving it on the tapered end of the arbor. A new bushing is the only thing required to adapt the arbor to a different size of hole. The arbor shown must be removed from the index-head spindle to change the work, as the work can be removed from the arbor only by driving it off. A nut may be placed back of the bushing, so that the work can be forced off without removing the arbor.

18. The most accurate arbor for use in the index-head spindle is made as follows: A solid arbor, with a shank fitting the index-head spindle is made similar to that shown in Fig. 9 (*a*). The collar, however, may be omitted or made only $\frac{1}{16}$ inch high.

The working end is made a tight fit in the work, into which it is driven, after which the work is machined as required.

19. Chuck Arbor.—The arbor shown in Fig. 10 would, perhaps, more properly be called a chuck, as it is used to hold work with a cylindrical part. The front end of the arbor is bored out to fit the work closely and its outside is turned tapering and threaded at the rear. It is split into three or more parts—four in this case—and has a sleeve nut *a* fitted to it, in which holes *b* are drilled to take the pin of a spanner wrench. The work, as, for instance, the bevel-gear blank *c*, is placed in the arbor and the nut *a* is screwed home with a spanner wrench; this causes the split end to hold the work centrally and grip it quite firmly. To hold the work securely, the cylindrical part of the work must be a fair fit in the hole of the arbor. The arbor shown can be adapted to a limited range of sizes by fitting concentric split bushings to it; the arbor cannot be expected in that case to grip the work as firmly as it does when no adapting bushing is used.

HOLDING WORK ON FACE PLATE

20. For many jobs, it is possible to use a face plate for holding the work. When the index-head spindle is threaded, the face plate can be screwed on it; when this is not the case, it may be fitted to a shank fitting the hole of the index-head spindle. If this is done, it is not advisable to use a thread for uniting the shank and face plate on account of the danger of unscrewing the face plate, unless a round key is sunk half into the shank and half into the face plate. A face plate screwed on the spindle requires the same precaution as a chuck; that is, whenever circumstances permit, the cut should be so taken as not to unscrew the face plate.

21. Work is fastened to a face plate and is trued up in the same manner as in lathe work; the pressure of the cut, however, is much greater than in lathe work, and hence the clamping must be done more securely. If circumstances permit, stop-pins may be inserted in the face plate to prevent slipping of the work, or stops may be bolted to it.

22. Lining of Face Plate.—Most of the face-plate work done in a milling machine requires the surface of the face plate to be at right angles to the axis of the milling-machine spindle. The setting may then be tested in the following manner: Place the index-head spindle in line with the milling-machine spindle, as is shown in Fig. 11, as nearly as can be judged by the eye. Fasten a bent piece of stiff wire, as *a*, to an arbor in the milling-machine spindle in any convenient manner, and by moving the saddle bring the pointed end in contact with the face plate, or, if desired, with a feeling piece *b* placed against the face plate. Revolve the milling-

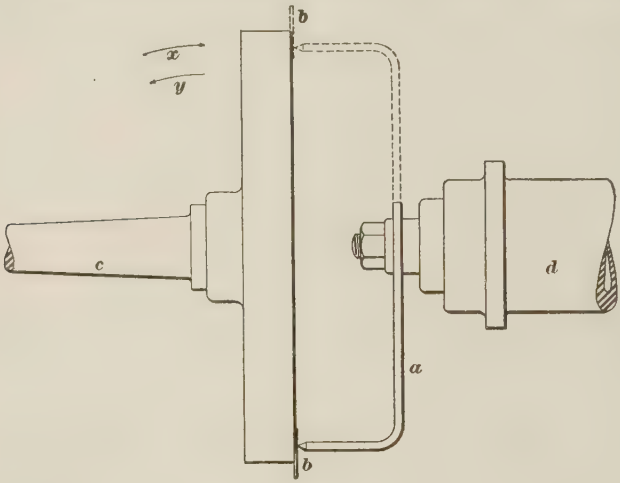


FIG. 11

machine spindle one-half revolution, thus bringing the point of the wire into the position shown by dotted lines, and test the distance between the end of the wire and the face plate. If it is greater than in the first position, the index-head spindle requires shifting in the direction of the arrow *x*; if it is less, the shifting must be done in the direction of the arrow *y*. Test next in two positions at right angles to those shown in the illustration, and shift the index-head spindle until the end of the wire remains at a constant distance from the face plate during a complete revolution of the milling-machine spindle.

23. Example of Face-Plate Work.—An example of circular milling that may be done with the work clamped to the face plate is shown in Fig. 12. The two slots a and b are circular; the slot a has its center of curvature at a' and the slot b at b', and the center of the work is at c. To mill the slots, the work must be set so that, for the slot a, the point a' will coincide with the axis of the index-head spindle; for the slot b, the point b' must coincide with the axis just mentioned. Fine center-punch marks may be made at these points; the work can then be trued up either with the face plate mounted on the milling-machine spindle or temporarily mounted in any suitable lathe that is available. The slots should be milled with an end mill; the feeding is then done by rotating the index-head spindle and the face plate.

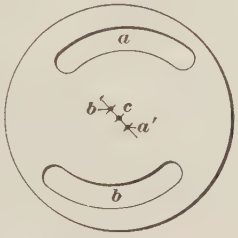


FIG. 12

HOLDING WORK IN FIXTURES

24. Purpose of Fixtures.—When a great number of equal pieces are to be finished by milling, and especially when so shaped that they cannot readily be held in the vise or on the table, they can often be held to advantage in devices called *milling fixtures*. A milling fixture should serve two different purposes; it must hold the work securely without distorting it, leaving the surfaces to be machined exposed to the cutter; and the act of clamping must automatically aline the work properly for the subsequent cutting operation. Milling fixtures may be constructed in a great variety of ways to suit the nature of the work, and no specific rules can be given as to their construction. A number of actual examples are here given, which will serve as suggestions of what may be done.

25. Splining Fixture.—The fixture shown in Fig. 13 is designed for holding shafts for key seating or splining, plain cutters being used for the purpose. It is intended for milling two shafts at once, but it can be used for machining one shaft at a time. A false table a is bolted to the milling-machine table

and has milled throughout its length two V grooves that are parallel to the line of motion of the milling-machine table. The shafts *b* that are to be splined or key-seated are laid in these grooves and are clamped by the clamps *c* and *d*; thus each shaft is held by two clamps at each clamping point. Owing to the way in which the clamps must be applied to be clear of the milling cutters *e*, one clamp would fail to insure a rigid holding of the work, as it would not hold the work with equal pressures against both sides of the V groove. This inequality of pressure is corrected by applying a second clamp opposite the first. The fixture is adapted for different sizes of shafts by making

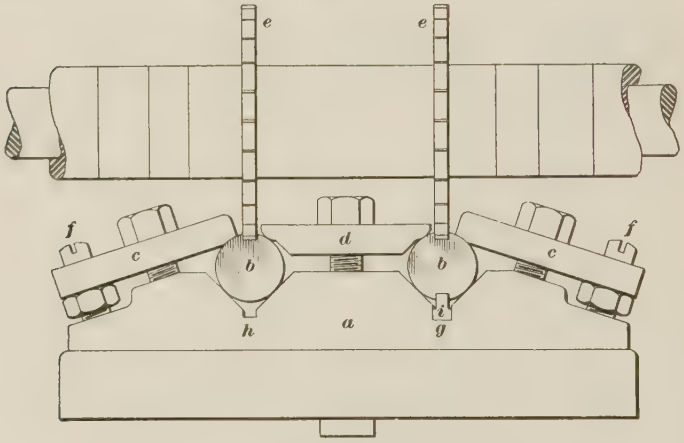


FIG. 13

the blocking for the clamps *c* adjustable for height. The blocking consists of studs *f* with nuts screwed on them; the clamps *c* have clearance holes for the studs to pass through, and rest on the nuts, which are screwed up or down to suit different diameters of work.

26. The fixture shown in Fig. 13 is so constructed that shafts may be lined up automatically so as to have two keyways cut diametrically opposite each other; but the design can readily be modified to cut the keyways at any angle with each other. A rectangular groove *g* or *h* is cut in the false table to receive the larger part of a two-size key *i*. The smaller part of the key

is made to fit the first keyway cut in the shaft, and the shaft is placed over it, as shown. The shaft is thus kept from turning and the second keyway is cut directly opposite the first.

27. Special Fixture.—The machine part shown in Fig. 14 (*a*) is to have a dovetailed groove *a* cut in the bottom parallel

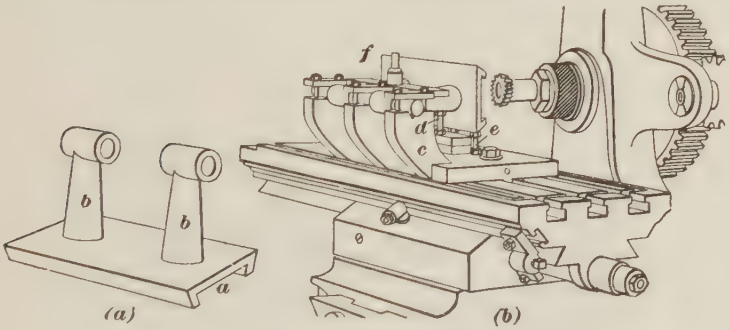


FIG. 14

with the axis of the two holes bored through the standards *b*. Owing to the shape of the work, it is rather difficult to hold it properly for machining, and it will become a rather expensive job if many such castings are to be finished. The work may, however, be securely held, quickly set, and automatically lined up by the use of the fixture shown in (*b*). The fixture consists of a body *c* bolted to the milling-machine table. It has three brackets with V grooves milled in the top of them in line

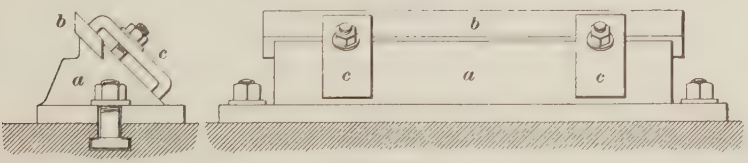


FIG. 15

with the line of motion of the table. A cylindrical mandrel is passed through the holes in the standards of the work and is then laid in the V grooves and clamped by the bolts and clamps shown. The free end of the work is lined up for height by means of the jack-screws *d* and *e*, and is finally confined by the clamp *f*.

28. Gib Fixture.—The fixture shown in Fig. 15 is designed for holding gibs to allow the angle on the edges to be finished with an end mill. It consists of a body *a*, which is bolted to the table and has its upper edge recessed to hold the gib *b* at the proper angle. Two clamps *c* are used for holding the gib to the fixture.

29. Multiple Fixtures.—A number of pieces may occasionally be held at one time in a fixture in order to have some

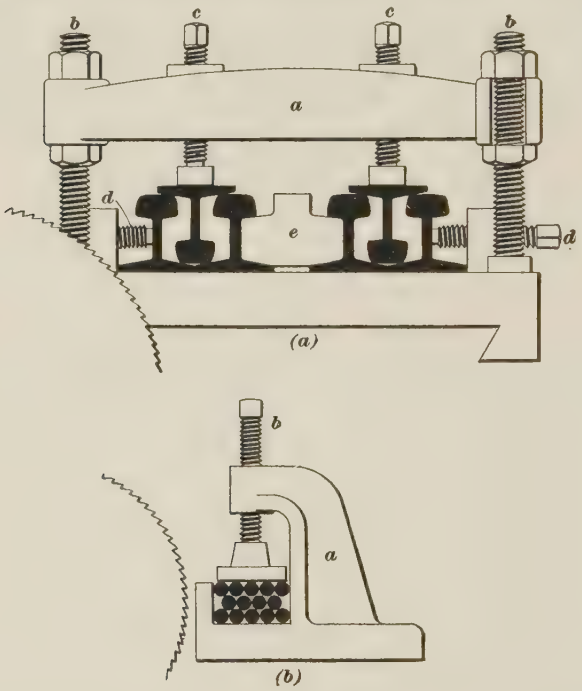


FIG. 16

simple milling operation performed on them, as for instance, the squaring up of the ends of rails, as shown in Fig. 16 (*a*), or of the ends of round work, as shown in (*b*). In (*a*), a yoke *a* is bolted to the table of the milling machine by means of the studs *b*. This yoke carries the setscrews *c*. The rails are confined sidewise by the setscrews *d*, which push each set of rails against the central packing-block *e*.

30. In Fig. 16 (*b*), a bracket *a* is bolted to the table of a milling machine; the bottom of the bracket has a rectangular opening in which the rods are placed and then confined by tightening the setscrew *b*. The act of tightening the setscrew causes the round rods to spread, so that the outer ones come in contact with the sides of the opening; as each rod is in contact with at least two others, they will all be held firmly.

WORK RESTS

31. Steady Rest.—Slender work is supported against the pressure due to the cut by a rest clamped to the table under the work. The steady rest most commonly used has a tongued

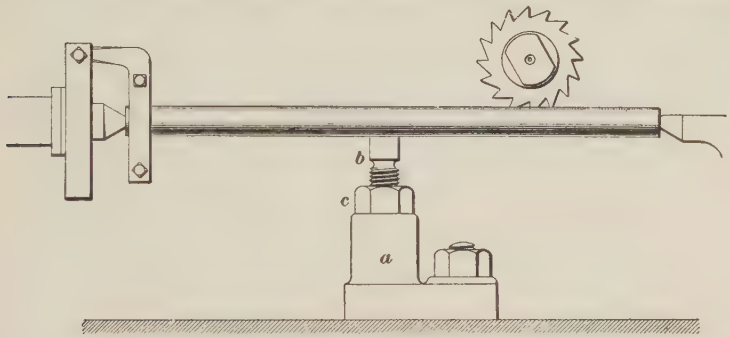


FIG. 17

base *a*, which is bolted in the slot beneath the index centers, as shown in Fig. 17. The top has a flat-headed setscrew *b* that is adjusted to any required height to support the work and is then secured by the clamp nut *c* when in contact with the work.

32. A flat-ended setscrew will support the work vertically but will not support it sidewise. For some classes of work, as for instance, when fluting small taps or tools held in a chuck, it is a decided advantage to support the work sidewise as well, as in that case the cut develops a sidewise bending action. For this purpose, the steady rest is made with a setscrew having a **V** or a half-round groove cut in its end as shown in Fig. 18. Such a setscrew should not be screwed into the base,

but should closely fit a hole reamed in it. A nut *c*, applied as shown in Fig. 17, is then used for bringing the setscrew in contact with the work.

Fig. 18

Fig. 19 shows an application of a steady rest with a **V**-ended setscrew to work held in a chuck; in this particular case, the work is a tap that is to be fluted. The screw is prevented from turning by splining it and putting a pin or key in the hole reamed in the base.

33. Limitations of Ordinary Steady Rest. The ordinary steady rest, of which the one shown in Fig. 17 is an example, will answer very well for comparatively stiff work, but as it supports the work at one point only it will, if the work is slender, still allow considerable bending of the unsupported parts during the cutting operation.

34. Universal Steady Rest.—The ideal steady rest will always support the work directly beneath the cutter throughout the entire length of the cut; this condition can be attained

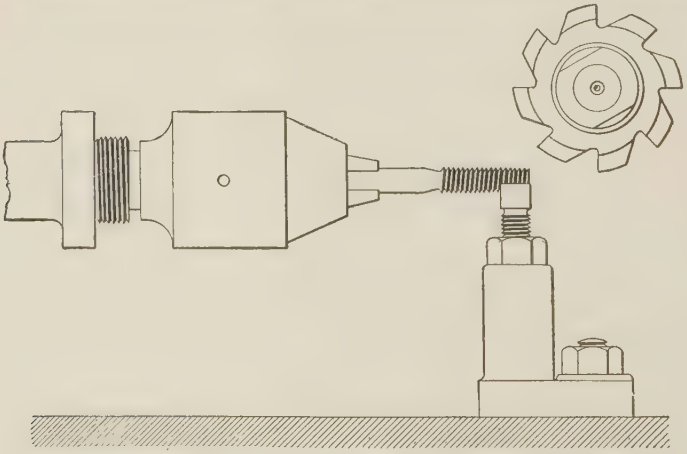


Fig. 19

by a steady rest made to suit the nature of the work, and so constructed as to support the work through its whole length.

35. A universal steady rest applicable to the full length of straight and tapered work may be constructed for a horizontal

milling machine as shown in Fig. 20. There are two bases *a* and *b*, which carry jack-screws and adjusting nuts. The ends of the jack-screws form eyes that are hinged to a supporting

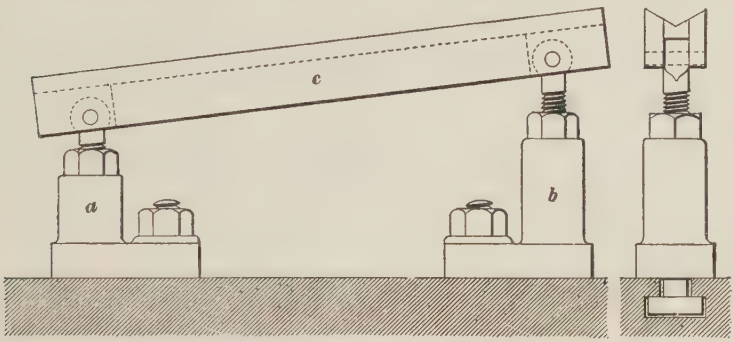


FIG. 20

bar *c*, which may have a V groove milled in its upper side or may be flat on top. As shown, it can readily be adjusted to suit taper work. Its range of usefulness can be extended by having several bars of different lengths.

SETTING OF MACHINE

ADJUSTMENT OF SPEED AND FEED

36. The general term **setting the machine** includes the selection of a proper cutting speed and feed, and arranging the machine for them; setting the cutter or cutters for depth, sidewise, and for width of cut; and adjusting the automatic feed to trip at the required point.

37. Adjustment of Speed.—After the cutting feed and speed have been selected, the driving belt and the feed-belt are placed on the proper steps of their respective cone pulleys. The determination of the proper step to use is a very simple matter when the number of revolutions that the milling-machine spindle makes with the driving belt on the different steps is known. This is found quickest by actually counting

for 1 minute, using a revolution indicator for the purpose. To find the number of revolutions corresponding to a given surface speed of the cutter, use the following rule:

Rule.—*To find the number of revolutions per minute of the spindle, multiply the cutting speed, in feet per minute, by 12, and divide the product by 3.1416 times the diameter of the cutter, in inches.*

The correct number of revolutions having been found, place the belt on the step that will give the nearest number of revolutions.

EXAMPLE.—With the belt on the smallest step of the cone pulley, the spindle makes 305 revolutions; with the belt on the second step, 178 revolutions; with the belt on the third step, 110 revolutions; and with the belt on the largest step, 68 revolutions. What step would be selected to give approximately a cutting speed of 80 feet per minute to a cutter $3\frac{1}{2}$ inches in diameter?

SOLUTION.—Applying the rule, the required number of revolutions per minute of the spindle is

$$\frac{80 \times 12}{3.1416 \times 3\frac{1}{2}} = 87, \text{ approximately}$$

As 68 is nearer to 87 than is 110, the belt would be run on the largest step. Ans.

In actual practice, an experienced operator will rarely stop to calculate the proper number of revolutions; his experience will tell him, as soon as he sees the material and the depth of cut to be taken, on what steps to place the driving belt and feed-belt. A careful operator, no matter how extensive his experience, should make it a rule to verify the accuracy of his judgment occasionally by calculation.

38. Adjustment of Feed.—The arrangement of the feed-mechanism differs so much in the various makes of milling machines that no specific rules for calculating the feed of the table per minute can be given. Nearly every modern milling machine uses a screw for feeding the table; with every such machine, the feed per minute may readily be calculated by the following general rule:

Rule.—*To find the feed in inches per minute, multiply the lead of the feed-screw by the number of revolutions per minute of the spindle, and divide the product by the number of revolutions of the spindle required to produce one revolution of the feed-screw.*

EXAMPLE.—In a certain make of machine, the spindle must make 2 revolutions to produce 1 revolution of the feed-screw. The lead of the feed-screw being $\frac{1}{4}$ inch, what is the feed per minute at 32 revolutions per minute of the spindle?

SOLUTION.—Applying the rule, the feed is

$$\frac{\frac{1}{4}\times 32}{2} = 4 \text{ in.} \quad \text{Ans.}$$

39. Construction of Feed Tables.—In practice it will as a general rule be found that the countershaft to which the machine is belted runs at a practically constant speed, so that the number of revolutions per minute of the spindle will remain constant for each speed; that is, if the spindle makes 32 revolutions with the belt on the largest step, it can safely be assumed that the spindle will make very nearly that number of revolutions whenever the belt is placed on the largest step. This fact makes it possible to construct an exceedingly convenient table of feeds per minute at the different speeds with all possible different changes of feed.

In the first place, observe how many revolutions of the spindle will be required for 1 revolution of the feed-screw with each change of feed; then apply the rule given in the preceding article to each possible speed of spindle and feed-change combination and tabulate the result for future reference.

40. Signs of Excessive Speed and Feed.—After the machine is started, watch the cutter to see that the speed is suitable, and watch the driving belt and the feed-belt to determine whether the feed is too great. Too high a cutting speed will be shown by a rapid dulling of the cutting edges, followed generally by a peculiar squeaking sound from the action of the dull cutter on the work; an excessive feed results in a slipping of the driving belt or the feed-belt, or both, and causes a shrill squeak to come from the belt. In extreme cases, one or both of the belts may run off the pulley.

SETTING THE CUTTER

41. Setting for Depth.—The machine can be adjusted to the correct depth of cut in two ways: by trial and by measurement. In an adjustment by trial, the cutter is set to about the correct depth and a cut is taken. According to circumstances, either the depth of the cut or the machined work is then gauged by gauges of suitable form, and the setting and taking of a cut are repeated until the work fits the gauge. The gauging device may be any suitable measuring instrument or a special gauge made for the purpose; duplicate work is milled almost entirely to limit gauges. When the work has a rather intricate form, setting the machine by trial is, as a general rule, the only method that can be employed, although in a few cases it may be possible to use the direct-measurement method.

42. When about to set a cutter for depth by measurement, the machine may be started and the work and the cutter carefully brought together until the cutter very lightly touches the work. Then, by observing the indication of the graduated dials reading to .001 inch, with which the feed-screws of the better kind of milling machines are supplied, and which turn these screws into micrometer screws, the work and cutter are brought together an amount equal to the depth of cut required.

The reading of the dial is taken when the cutter is just touching the surface of the work; the required depth of cut is then added to, or subtracted from, this reading and the machine is set to the calculated new reading. It will be understood that before the depth of cut is adjusted, the work is run clear of the cutter. The micrometer graduations are also very useful for adjustment by gauging, since they allow the depth of cut to be increased by a definite amount. For instance, if the measurement of a piece of work shows it to be .007 inch too thick, the graduations allow the work to be raised, or the cutter to be lowered, by just that amount. All the lost motion in the feed-mechanism must be taken up before bringing the work in contact with the cutter.

43. In setting the machine for depth of cut, it is not always possible to measure from the surface to be machined, owing to its being rough and uneven. In most cases there is some finished surface parallel to the proposed cut in contact either with the bottom of the vise, or the surface of the milling machine, or of an angle plate, or of some special fixture from which measurements can be taken to the cutter. Then, the cutter may be set for depth by testing with a scale, a surface gauge, a height gauge, or some similar convenient device, measuring from the finished surface.

44. A surface gauge may be used as shown in Fig. 21 for testing the setting of the cutter. In this case, a plain cutter

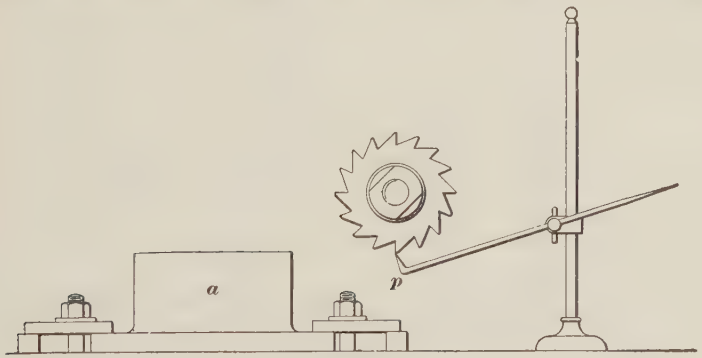


FIG. 21

is employed, and the problem is to set it so that the work *a*, when finished, will be a certain height. The pointer *p* of the surface gauge may be set by the aid of a steel rule to the given height above the surface of the milling-machine table, and then used for testing the height of the cutter. To do this, the cutter should be placed in such a position that a line drawn through one of its cutting edges and the center of the cutter is at right angles to the surface of the table, and hence the cutting point of the tooth will be at its lowest position. The pointer of the gauge is now placed beneath the cutting edge selected and the table raised until the cutting edge and the pointer touch. The cutter is then set correctly.

45. When a surface gauge is not available, and a steel rule cannot be used because of the interference of the arbor, a combination of one or more size blocks supplies a very accurate method of adjusting the work and the cutter. The cutter is set as when a surface gauge is used, and the adjustment is made so that the size block will just pass between the cutter and table.

46. The special surface gauge shown in Fig. 22 (*a*) will be found of advantage for machines that have no graduated dials, when a cutter is to be set for a given depth of cut. It differs from the ordinary surface gauge, in that it carries two heads and pointers. In use, the pointer *p* is set to touch the

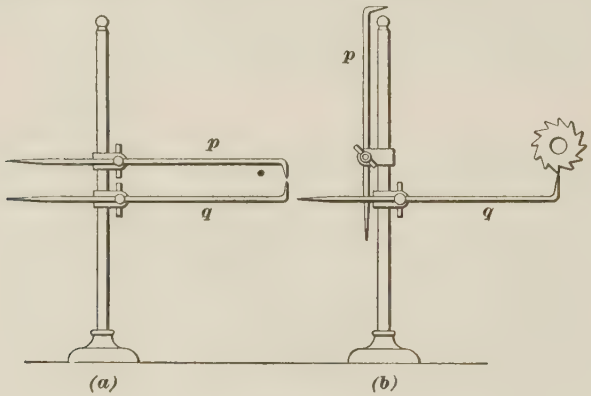


FIG. 22

surface of the work; the pointer *q* is now adjusted until the distance between it and the pointer *p* is equal to the required depth of cut, when *p* is swung up out of the way and *q* is used for testing the setting of the cutter, as shown in (*b*).

47. A careful operator will always gauge the setting of the cutter as soon as it cuts the full depth for which it is set, in order to make sure of the setting. Whenever this is done, the machine should be stopped to prevent any accident during gauging. In work done between index centers, it often occurs that the bottom of the cut must be at an exact distance from the axis of the work. In this case, the cutter may first be set to touch the work, and then set to a depth equal to the

difference between the radius of the work and the required distance from the center.

48. In some instances, calculation will be necessary to obtain the correct distance from the axis from which to compute the correct depth of cut. For instance, assume that a gear is to be cut with a cutter that requires to be sunk in to a depth of .27 inch when the diameter of the gear blank is exactly 5.25 inches. On measuring the gear blank, it is found to be only 5.23 inches; it is required to find the depth to which the cutter is to be set in order to preserve the correct distance of the bottom of the cut from the axis. The correct distance, evidently, is $\frac{5.25}{2} - .27 = 2.355$ inches. The radius of the actual gear blank is $\frac{5.23}{2} = 2.615$ inches. Then, the depth of the cut for which the machine is to be set is $2.615 - 2.355 = .26$ inch.

49. Setting the Cutter Sidewise.—In setting a cutter sidewise, several cases occur in practice. For example, the cutter may be wider than the work, and the cut may have to be taken over the whole surface; the cutting may have to be done to a shoulder; or the cutter may have to be set central with the index centers or index-head spindle.

FIG. 23

Considering the first case mentioned, the cutter can be set sidewise by eye alone, and no special directions are required. In the second case, which occurs chiefly in duplicate work of intricate shape, the cutter may be set correctly by trial or by measurement. As a general rule, the distance of the shoulder from some edge of the work is either accurately or approximately known, and the cutter can be set quite accurately by measurement, gauging after the cut has been taken. In setting by measurement, a

steel rule may be applied between the end of the cutter and the side of the work, as shown in Fig. 23, where the dotted lines show the depth and location of the cut to be taken over the work *a*.

50. Setting the Cutter Central and Off Center. A cutter may be set central, in respect to work held in a chuck or between centers, in several ways. A very simple way often used in horizontal machines is shown in Fig. 24. The work is placed between the centers or in the chuck, and a try square *c* is then set on the table with its blade in contact with the work.

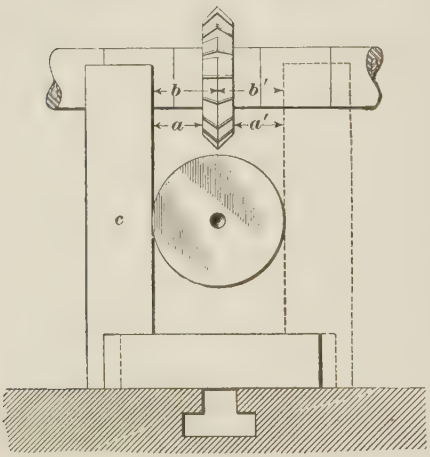


FIG. 24

If a plain slotting cutter is to be set, the distance *a* from the blade of the square to the side of the cutter is measured. The square is then placed on the other side and the distance *a′* is measured. If these two measurements do not agree, the work is adjusted and the measurements are repeated until they are the same on both sides, when the cutter will be central. If the cutter is symmetrical, like a center-line gear-cutter or a double-angle cutter with equal angles, the distance from the blade of the square to the center line of the cutter, as at *b*, is measured. The measurement is then made at *b′* and the cutter is adjusted until these distances are equal on both sides. Cutters that are not symmetrical always have some well-defined edge that is brought central, or from which measurements are made. If the table is arranged to swivel, it should be set to zero before setting the cutter.

51. Double-angle cutters with unequal angles often require to be set a given amount off center. To do this, set the cutter central and then move the work or the cutter sidewise by the

amount required, using either a steel rule and measuring from the blade of a try square or the graduated feed-screw dial if one is available. An approximate way of testing the central setting of a cutter in a horizontal miller is by means of one of the index centers. The table is set to zero, so that the line of motion is at right angles to the axis of the cutter, and the knee is raised until the center used for testing is about on the same level as the cutter. The milling-machine table is now shifted sidewise until the part of the cutter that is required to be central is in line with the index-center point, as nearly as can be judged by eye. While this method of setting is not the most accurate one that can be devised, it will be sufficiently accurate for the greater part of the work that is to be done.

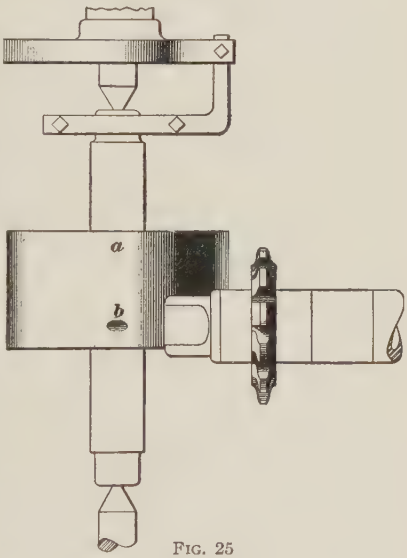


FIG. 25

52. Another fairly accurate way of testing the setting is shown in Fig. 25, which is a top view. The work *a* is placed between the centers and the cutter and the work are brought together until they touch slightly. The cutter, while revolving, is then fed across the work, or vice versa, in the direction of the axis of the cutter, thus cutting out a small elliptical spot *b*. The cutter is now set central with this spot by eye. If the work runs very true, this method is as accurate as the one previously described.

53. One of the most accurate methods of setting the cutter central for work held either in the chuck or between centers that are in line, is as follows: Any round piece of iron or soft steel is held in the chuck set either vertically or horizontally. The cutter is then set as nearly central as possible by eye and

brought in contact with the work while rotating, which makes a light cut. The work is given exactly one-half turn and the cutter is brought up to the piece again, which will cut the notch slightly wider. The cutter is then set central in this notch and a cut is made through the piece, by using either the vertical or the horizontal feed. The piece is run back, given another one-half turn, and another cut is made without disturbing the setting. The cutter is then set central in the groove and a deeper cut is taken, followed by another half turn of the work. This is repeated until the cutter removes no metal from either side after the work is turned. The cutter then will be exactly central.

54. When an end mill is to be set central to work held between centers, in either a horizontal or a vertical machine, the problem, in reality, is to make the axes of the work and the cutter intersect. The machine may be set correctly by placing a true-running milling-machine arbor *a* in contact either with the work *b* or with a true-running mandrel placed between the centers, as shown in Fig. 26, using a piece of thin tissue paper between them as a feeling piece. Remove the arbor and then shift the table or the spindle an amount equal to the sum of the radii of the work and the arbor. If this method of setting is used in a horizontal or a vertical machine, the centers must be in line vertically and horizontally. It is customary to make a horizontal mark on one of the angular surfaces of the column so that it coincides with the top of the knee when the index-center axis coincides with the cutter axis, and the word CENTER is stamped just above the line. A similar line could be placed on the horizontal cross-slide of a vertical machine to show when the two axes coincide.

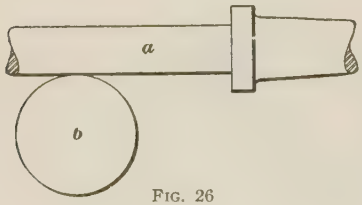


FIG. 26

55. In vertical machines, the central setting of an end mill may also be tested by placing a try square on the table

with its blade against the work, measuring from it to the cutter, and then placing the square on the opposite side of the work and repeating the measurement until the tests show the same distance on both sides. Any cutter placed on an arbor when applied to work held between the centers, is, as a general rule, applied on the side. The central setting of such a cutter may be tested by taking cuts across the face of a piece held in the chuck, as was explained in Art. **53.** Another method is to set the cutter central by one of the center points, just as is done in a horizontal milling machine. A third and very convenient method is to measure the height of the index centers above the milling-machine table while they are horizontal and set the cutter center to the same height.

56. Adjusting Straddle Mills for Width.—The distance between the sides of a pair of straddle mills is adjusted by means of washers. Where rather delicate adjustment for width is required, paper washers of different thickness may be used to good advantage. Good thicknesses to have handy are .001 inch or very thin tissue paper; .002 inch, fine writing paper; .004 inch, heavy writing paper; and .008 inch, medium heavy manila wrapping paper. In addition, sheet-brass or sheet-steel washers .016 inch and .032 inch thick will be found convenient. In some shops thin sheet-steel washers are used exclusively; thin sheet steel rolled very exactly to size may now be obtained in thicknesses from .002 inch up. The final adjustment for width of cut for straddle mills must be made by trial whenever the limit of variation is very small; that is, after setting the cutters as accurately as possible, a cut is taken and the width measured. The distance between the cutters is then adjusted in the direction indicated by the measurement.

57. Arranging Gang Mills.—In assembling a gang of mills on an arbor, it is advisable to place them in such relation to one another that the cutting edges of adjacent mills will not lie in the same line. If so placed, the width of the cut will not be excessive, and the effect will be almost the same as that of a cutter with helical cutting edges; that is, the intensity of the shock due to a cutting edge engaging the work is greatly reduced.

ADJUSTMENT OF AUTOMATIC FEED

58. Every modern milling machine that has an automatic feed has a tappet in a slot at the side of the table. This tappet may be adjusted to trip the feed—that is, to stop the feed —at any point within the range of motion of the table. The easiest way of finding the correct position of the tappet is to loosen it and bring it in contact with the stop, then run the table into the position where the cutter just finishes the cut, and tighten the tappet. If it is necessary to have the feed trip at a certain point, the tappet is first set to trip the feed a little short of this point and the machine is started. The point where the feed stops is then observed and the tappet is adjusted by repeated trials until the feed trips at the right place.

TAKING THE CUT

DIRECTION OF FEED

59. Methods of Feeding.—There is a difference of opinion among builders of milling machines as to the direction the feed should have with respect to the direction of rotation of the cutter. Most builders are in favor of feeding the work *against* the cutter; that is, with the cutter rotating in the direction of the arrow x, Fig. 27, they hold that the work a should be fed in the direction of the arrow y. In this case, the tendency of the cutter is to push the work *away* from it. On the other hand, other builders are in favor of feeding the work *with* the cutter; that is, if the cutter revolves in the direction of the arrow x, they feed the work b in the direction of the arrow z. In this case, there will be a tendency to draw the work toward the cutter.

60. It is by no means settled as to which method of feeding will produce the best results. Under proper conditions just as good results can probably be secured with one method as with the other. It must not be inferred, however, that a machine

built and intended for feeding against the cutter is, without further preparation, adapted for the other way of feeding. As previously stated, by feeding the work *with* the cutter, there will be a tendency to draw the work toward the cutter. Taking a machine arranged for feeding against the cutter and attempting to feed with the cutter, the latter will suddenly draw the work toward it at the beginning of the cut to an extent depending on the amount of backlash between the feed-screw of the milling-machine table and the nut in which it works. The cutter will consequently climb up on the work; then the cutter will break, the arbor will be bent, or the work will be broken. In either case, the result is exactly what might have been anticipated.

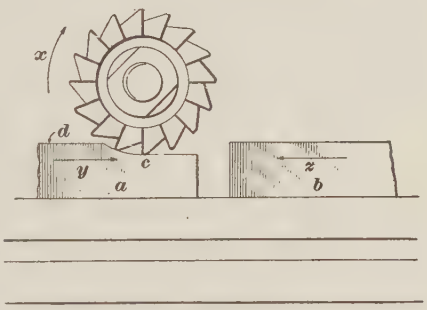


FIG. 27

61. The whole trouble is due to the backlash always existing between the feed-screw and its nut; by taking up the backlash in the proper manner, or, more correctly speaking, by transferring it to a place where it can do no harm, a machine built to feed *against* the cutter can be made to feed *with* the cutter. The usual and most obvious way to prevent the table from jumping forwards is to hold it back by a heavy weight suspended from a cord or a chain fastened to the table and passed over a pulley placed in line with the table. A milling machine arranged to feed *with* the cutter, can be used with impunity for feeding *against* the cutter, because there is no tendency for the work to jump toward the cutter.

62. Milling Work With Hard Surface.—When the work to be milled has a hard surface, as iron castings, steel castings, and some forgings, or has a surface in which sand is embedded, as is the case with brass and similar castings that have not been pickled, the general opinion seems to be that it is better to feed the work against the cutter, as then the cutting

teeth will get beneath the hard surface, and, working in the soft metal, will keep sharp much longer.

63. Assume the tooth *c*, Fig. 27, to be cutting and the surface *d* of the work to be covered with a hard scale. The tooth *c* comes up from below the scale and instead of cutting through it, will pry the scale off and crumble it. A prominent firm states, as the result of experiments in feeding *with* the cutter and *against* it when milling iron castings having a hard scale, that by feeding against the cutter, the latter lasted, without sharpening, eight times as long on an average as when feeding with the cutter. When the work to be milled is of uniform hardness throughout, the objection of dulling the cutter rapidly by feeding with it disappears, and just as good work can be done by feeding *with* the cutter when everything is properly arranged for that system of feeding.

APPLICATION OF CUTTER

64. General Rule.—The one general rule in regard to taking the cut that applies to either system of feeding, may be stated as follows: *Always take the cut in such a manner that the cutter cannot draw the work toward itself.* In other words, whenever possible, the feed and the machine should be arranged so that neither the cutter, the work, nor the machine will be damaged by any slipping of the work. The universal milling machine is used to make cuts with or against the cutter when the cuts are vertical. The reason for this is that the backlash is taken up by the weight of the knee and the table, so that there is no tendency for the cutter to dig in or draw the work toward itself.

65. Influence of Spring.—The example given in Fig. 28 brings out some points to be considered in determining the proper direction of the feed. In this case, a cylindrical piece of work is held in the chuck and it is required to cut a rectangular groove, the bottom of which is shown by the dotted line *a* across the end of the work. With the cutter rotating in the direction of the arrow *x*, and feeding in the direction of the arrow *y*—that is, feeding *with* the cutter—there will obviously

be a tendency to draw the work toward the cutter. Now, while the backlash may be transferred to a place where it will do no harm, by a suitable counterweight, it is impossible to get rid of the spring of the work itself, and of any spring that may exist in the index head carrying the chuck.

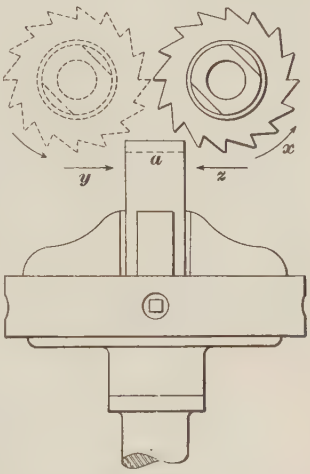


FIG. 28

66. With the cutter rotating as shown by the arrow *x*, it should be to the left of the work, or in the position shown by dotted lines, and the work should be fed *against* the cutter, as shown by the arrow *z*. The work will then spring *away* from the cutter, and there will be no danger of its catching and breaking the latter. From this example, it is learned that the spring of the work and of the attachment in which it is held must be taken into consideration, and that allowance must be made for it in determining the proper direction of feed.

67. Example of Feeding With Cutter.—Occasionally it is a decided advantage to feed *with* the cutter when the machine can be arranged to allow this to be done. Thus, for instance, consider the piece *a* shown in Fig. 29 to be held in the vise and resting on the packing-block *b*. The upper surface is to be roughed down to the dotted line shown. With the cutter revolving in the direction of the arrow *x* and feeding in the direction of the arrow *y*, the pressure of the cut is mainly downwards, there being no tendency at all to lift the work. In consequence, the work

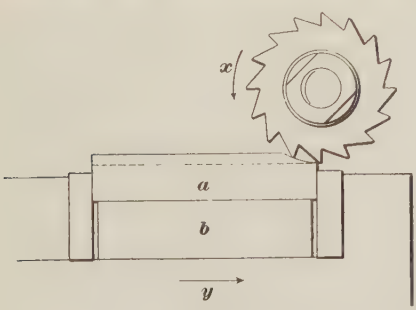


FIG. 29

will be pressed firmly against the packing-block. No attempt should be made to take a cut in this manner unless the machine is arranged to suit this method of feeding by having a feed-screw and nut without backlash, or by having the backlash taken up by a counterweight.

68. Slipping of Work.—The example given in Fig. 30 shows that there is occasionally a right and a wrong way of applying the cutter to the work, even after adopting the proper direction of feed. In this case, it has been determined to feed against the cutter; the work *a* is held between the vise jaws, as shown, and a cut is to be taken at an angle other than 90° with the top surface of the work. This particular job occurs in making forming tools for fly cutters and formed milling cutters. The depth and direction of the cut are given by the dotted line *b*.

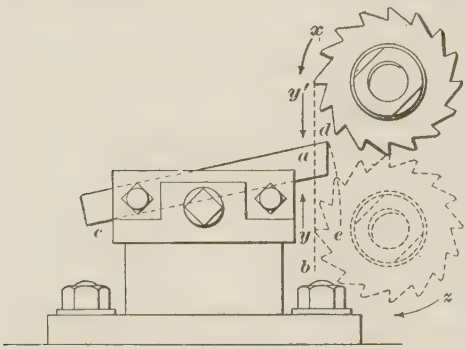


FIG. 30

With the cutter above the work and rotating in the direction of the arrow *x*, to feed against the cutter the feed must be as shown by the arrow *y*. While feeding in this manner, assume that the work slips, as is very liable to happen. Then, the work will rotate about a point somewhere near *c*, and the end operated on will move in an arc about as *d e*, or toward the cutter. The natural result will be that something must give way, and either the cutter or the work, or both, will be ruined. To overcome the evil effect of slipping, the cutter should, in this case, commence to cut at the bottom; it should revolve in the direction of the arrow *z* and the work should be fed in the direction given be the arrow *y'*. In case of slipping, the work will then move *away* from the cutter and there is little likelihood of its being spoiled by it.

69. The rectangular work *a* shown in Fig. 31 requires a slot to be cut in its end, the depth of the slot being indicated by the curved dotted line *b*. If a horizontal machine is used, and the work is at all long, it must be held in the vise so that its surfaces *a'* and *a''* are in contact with the vise jaws. No choice of the direction of the feed is possible in this case; it must be in the direction indicated by the arrow *y*. Now, considering the direction of rotation of the cutter, it may be as shown by the arrow *x* or the arrow *z*; in the latter case, of course, the cutter would be reversed.

70. In the case shown in Fig. 31 the evil effect of slipping of the work cannot be overcome; for, in whatever way the cutter

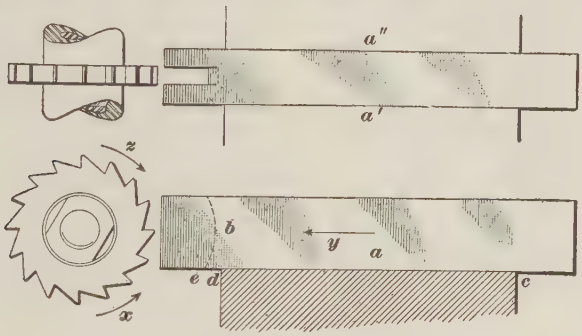


FIG. 31

rotates, the catching of the cutter due to excessive feeding will not push the work out of the way, but will either lift up or depress the end operated on. If slipping occurs, it would better take place in an upward direction, as the work will then rotate about the corner *c* of the vise, and the corner *e* of the slot will rapidly come clear of the cutter. In order that slipping shall take place in this manner, the cutter must revolve in the direction of the arrow *x*. Now, assume that the cutter revolves in the direction indicated by the arrow *z*. Then, should the work slip, its end will rotate downwards about the corner *d* of the vise; that is, it will be drawn in between the vise and cutter with results that are likely to be disastrous to the vise, cutter, and work. From the foregoing explanations, the con-

clusion may be drawn that when it is impossible to make the work slip *away* from the cutter, everything should be so arranged that slipping will do the least possible amount of damage.

STARTING THE CUT

71. After the machine has been adjusted so that the cutter will take the desired depth of cut, the machine is started and the cutter is brought almost in contact with the edge of the work. The cut is then started either by throwing in the automatic feed or by careful feeding by hand. The method of starting the cut by means of the automatic feed is preferable, as there are less chances for an accident. When a cut is started

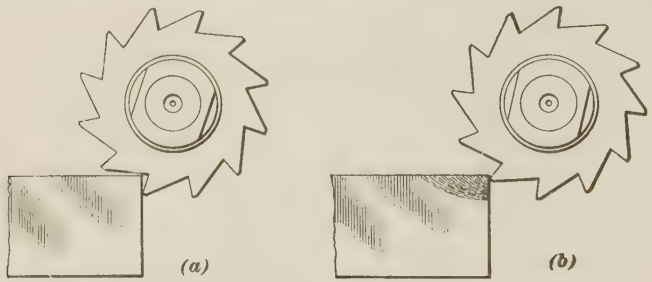


FIG. 32

by hand, any carelessness may result in pushing the work in deeply between two teeth of the revolving cutter, as shown in Fig. 32 (*a*), with the result that the cutter will be broken, or the work spoiled, or both. But, if the automatic feed is used, or very careful hand feeding equivalent to automatic feeding is done, the teeth of the cutter will approach the work gradually and take successive, easy cuts, as shown in (*b*), without undue straining of the cutter and the work.

SLOTTING WITH END MILLS

72. In cutting slots or grooves with end mills, three cases arise in practice, as follows: Cutting from the solid metal; finishing in one operation two sides of a slot that has previously been roughed out; and finishing each side of a slot separately.

73. Slotting From Solid Metal.—When cutting a slot or a groove out of the solid metal, as is shown in Fig. 33, either a right-hand or a left-hand cutter may be used. The direction of the feed in respect to the rotation of the cutter is only influenced by the manner in which the cutter must turn in order to cut. Considering a left-hand cutter, as shown in (*a*), which is a view looking *toward* the spindle, it can be seen that the cutter, which naturally has a tendency to spring away from the cut when cutting on the side *a*, will crowd upwards, as there is always some spring to an end mill. As a consequence, the slot or groove will be slightly above the position for which the cutter is set. When the cutter approaches the work so

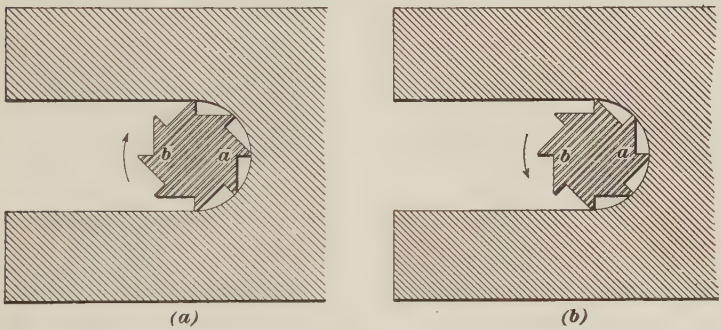


FIG. 33

that its side *b* is cutting, the cutter will crowd downwards; the slot or groove will then be cut slightly below the position of the cutter. When a right-hand cutter is used, as shown in (*b*), and when feeding so that the side *a* does the cutting, the cutter will crowd downwards. Should the side *b* do the cutting, it will crowd upwards.

74. A slot or groove cut from the solid metal and not finished any further must not be expected to be very true throughout its length. The reason for the deviations from truth that will be found lies in the fact that the metal operated on, no matter how good it may be, is neither perfectly homogeneous nor of uniform hardness. As a result, the cutter will crowd over to a varying extent, and consequently the sides

will not be true; hence, a slot or a groove cut with an end mill should always be finished by milling either both sides simultaneously after roughing out, or each side separately.

75. Finishing Slots in One Operation.—When both sides of a slot or groove are to be finished simultaneously, the cutter must have a diameter equal to the finished width. The mistake of setting the cutter in such a manner that it will take cuts of equal depths must be avoided, if good work is desired. This mistake is so common that many persons doubt seriously the possibility of milling true and nicely finished slots and grooves with an end mill.

76. A groove that is being finished with a left-hand end mill set central with respect to the roughed-out groove is shown

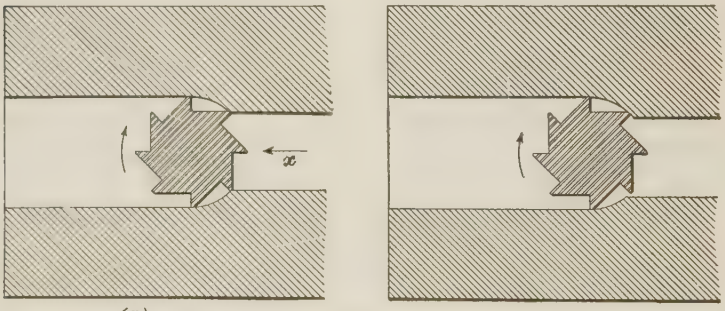


FIG. 34

in Fig. 34 (*a*). In this case, the feeding takes place in the direction of the arrow *x*. Considering the teeth of the upper half of the cutter, it is seen that the feeding is done *against* the cutter; considering the lower half of the cutter, the feeding is seen to be *with* the cutter. Now, during feeding, there will be, at the bottom, a greater tendency for the cutter to draw the work toward itself than there will be at the top to push the work away; if the work cannot move, the cutter will spring forwards and the result will be either broken teeth or a rather ragged groove, in case the teeth are strong enough to stand the strain. When the amount of metal removed is very small, the evil effects of this manner of setting are

naturally not so pronounced as in cases where a fairly heavy cut is taken.

77. The proper way of setting the cutter is shown in Fig. 34 (*b*). Here the cutter is set so that the depth of cut on the side where the feeding is done against the cutter is about twice as great as on the other side; hence, the tendency of the cutter to jump forwards is overbalanced by the resistance due to the greater depth of cut, and the result will be a fairly smooth and true groove. From the foregoing statements, the conclusions are to be drawn that when a smooth and true groove or slot is to be finished on both sides with an end mill, the groove should be roughed and the finishing cutter set so that a greater amount of metal will be taken off by the teeth on the side fed against than on the side fed with the cutter.

78. Finishing Slots in Two Operations.—Many milling-machine operators hold the opinion that the best results in cutting slots and grooves with end mills can be obtained by finishing each side separately; this involves using a milling cutter a little smaller than the finished size. Whenever possible, the roughing out should be done with a plain cutter, which can be crowded harder and will cut faster than an end mill, chiefly because it is more rigid.

FEEDING INTO CORNERS

79. Undercutting by Plain Cutter.—When taking a shallow cut against a high shoulder, or *feeding into a corner*, as it is called, it will be found, as is shown in Fig. 35, that the curved shoulder cut by the cutter, instead of being level with the bottom *a* of the cut, or as shown by the dotted curve, falls below the bottom, being about as shown by the full curved line. The reason for this is that no matter how stiff an end cutter or a cutter arbor may be, it will still spring to a certain extent under the action of a relatively small force. In the case of feeding into a corner, the pressure on the arbor due to the cutting operation is about in the direction of the arrow *x*; that is, there exists a tendency to draw the cutter to the work, and

since the arbor can yield, the cutter will be drawn in enough to show distinctly the undercutting illustrated.

80. Undercutting is least marked with a low shoulder, but rapidly increases as the height of the shoulder becomes greater. It can be partly overcome by using a stiffer arbor, or, if possible, by supporting the arbor by an outboard bearing. It can be entirely overcome, however, only by taking the cutter slightly away from the work, or vice versa, when the shoulder is almost reached. This naturally calls for some skill and judgment on the part of the operator; the exact amount that the cutter and work must be separated can be determined only by experiment in each particular case.

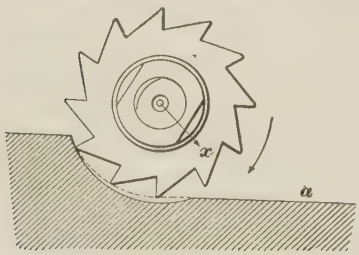


FIG. 35

81. Undercutting by End Mill.—Undercutting shows itself to a more marked degree at the end of a slot cut with an end mill, as shown in Fig. 36. As previously stated, the cutter shown will crowd upwards, and, hence, its actual path will be given by a line, as *a*, while *b* represents the path of the cutter for which the machine is set. When the cutter is at the end of the slot—that is, when the feed has been stopped—it will tend to spring back to its normal position, and, in consequence, it will cut under until all spring is gone. The undercutting can be prevented by stopping the machine, without tripping or throwing out the feed, and moving the work away from the cutter in the direction of the cutter axis.

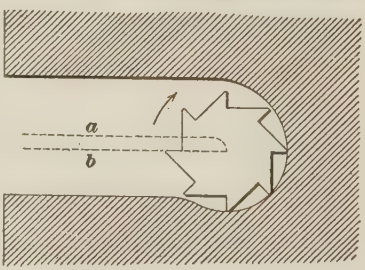


FIG. 36

82. Suppose that, in Fig. 36, the feed is reversed when the cutter has reached the termination of the groove, or slot.

Then, as in this operation the cutter is slightly below the lower surface, it will be cut away to some extent when the cutter is fed over it again, thus widening the groove. From this it follows that if a milling cutter is used for cutting two sides of a groove at once, it will, if fed over the work in opposite directions, cut a path wider than its own diameter.

REVOLUTION MARKS AND BRACING

83. Cause of Revolution Marks.—If a surface milled with a side, face, or end mill is carefully examined, it will be found to bear circular marks, with the circles equally spaced. The distance between the circles or marks is generally equal to the movement of the work for 1 revolution of the cutter; on this account the general name of *revolution marks* is applied to the collection of marks distinctly due to the end-milling operation. Revolution marks may be caused by a cutter that does not run absolutely true, a yielding machine, springy work, the use of too light an arbor, end play of the spindle, or to a combination of two or more of these causes.

84. The width of each revolution mark seems to depend entirely on the amount of feed per revolution; from this it follows that lessening the feed will cause smoother milling. When the feed is decreased, the speed of the cutter may be increased. The depth of the revolution marks depends on the amount of vibration existing, and as the vibration is chiefly due to the fact that the cutter does not run absolutely true, an attempt to reduce the depth should commence with truing the cutter. This should be followed by supporting the straddle mill or the side cutter, whenever circumstances permit, by means of an outboard bearing, which in turn should be rigidly braced after the machine has been set for the correct depth of cut.

85. Reduction of Revolution Marks.—Revolution marks can be reduced by a true-running cutter, well supported work, and a properly braced machine, but they will never entirely disappear; for, no matter how well the bracing is done nor how stiff the machine, there will still be some vibration.

Furthermore, no matter how true a cutter is ground, it will not stay true. It is a practical impossibility to harden a cutter so that all of its teeth will be of exactly the same hardness; consequently, the softer teeth will wear down faster than the hard ones and the cutter will soon run slightly out of true.

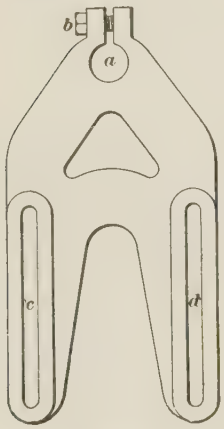


FIG. 37

86. Bracing.—Most modern machines are supplied with braces that will tie the outboard bearing either directly to the frame or to some machine part that in turn can be clamped to the frame. Most commonly, two slotted braces are bolted to the knee; a clamping bolt then passes through the slots of the braces and ties them to the outboard bearing. Fig. 37 is a common design intended for a horizontal machine. The brace is an iron casting; a hole *a* is bored at the top to fit a projecting shoulder of the outboard bearing, to which it can be clamped by means of the bolt *b*. Stud bolts are screwed into the face of the knee and pass through the slots *c* and *d*; they carry nuts and washers and are used to clamp the brace to the knee. The slots in the brace allow the knee to be adjusted for height.

87. Chatter Marks.—Chatter marks are wavy or mottled surface marks on work milled with plain or formed cutters. They are due to the spring of work, tool, and machine, and are prevented largely by the methods used for the prevention of revolution marks.

MILLING-MACHINE WORK
(PART 4)

OPERATION OF MILLING MACHINE

INDEXING

DEFINITIONS

1. In connection with milling-machine work, **indexing** refers to the process of dividing a circle into equal or unequal divisions by means of milling-machine attachments, or a line into divisions by the use of the feed-screws of the milling machine. When applied to circles, the process is known as *circular indexing*, and the attachment is called an *index head*, or *dividing head;* when applied to straight lines, the process is known as *linear indexing* and is usually performed with a feed-screw in connection with a pointer and a graduated dial.

2. There are two methods of circular indexing, known as *direct indexing* and *indirect indexing*. The latter is divided into three classes, namely, *simple indexing*, *compound indexing*, and *differential indexing*.

DIRECT INDEXING

3. Direct Index Head.—Direct indexing is done by the use of an index plate secured to the index-head spindle. The index plate has one or more circles of holes drilled into or through it, and a pin mounted on the frame serves as a stop

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when it enters a hole in the plate. An index head for direct indexing is shown in Fig. 1. The index plate *a* is keyed to the spindle that carries the work center *b* and a driving or face plate *c*. The indexing pin *d* is adjustable in the vertical slot *e* so that it can be made to register with any one of the circles of holes in the side of the plate *a*. Indexing is performed by withdrawing the pin *d* from the hole in the plate, rotating the plate with the spindle and the work through the required arc, as determined by counting the holes in the circle used and then inserting the pin in a hole. A clamp screw *f* is used to grip the spindle in one of its bearings so as to relieve the pin *d* and the

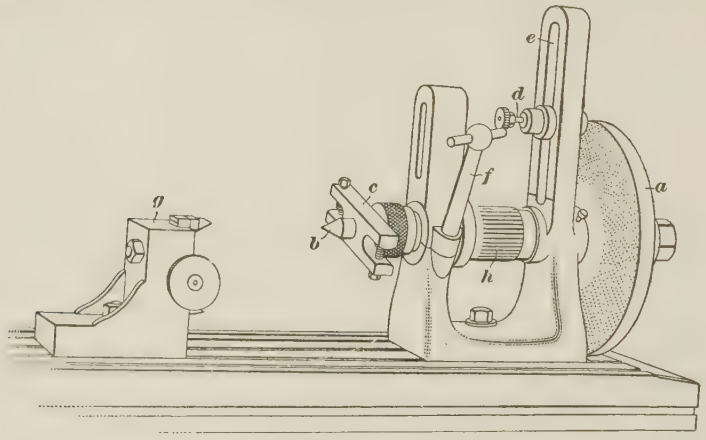


FIG. 1

index plate from any pressure during the milling. A tailstock *g* completes the equipment that is bolted to the milling-machine table for supporting work between centers. A hand nut *h* provides for longitudinal adjustment of the spindle so that the center *b* may be moved when mounting or taking out the work. This entire attachment is usually called *plain indexing centers*. The centers may be supported on raising blocks so as to accommodate work of large diameter.

4. Circle for Direct Indexing.—With a direct index head, a circle must be chosen that has a number of holes exactly divisible by the number of spaces required, and the quotient

obtained by performing this division is the number of holes that the plate must be moved at each indexing. Suppose that the index plate has three circles containing 24, 30, and 36 holes, and that 9 equal spaces are desired. The 36-hole circle would be used, because 36 is the only one of the three numbers that can be exactly divided by 9; and as $36 \div 9 = 4$, the plate is moved 4 holes at each indexing. To obtain 10 equal spaces, the 30-hole circle would be used, and the plate would be moved $30 \div 10 = 3$ holes at a time. With the indexing centers shown in Fig. 1, two index plates are regularly furnished with rows of holes suitable for making all even divisions up to 100 and all odd divisions up to and including 49. For any additional range of work, special plates are necessary.

SIMPLE INDEXING

5. Indirect Indexing Mechanism.—An index plate is employed in indirect indexing, as well as direct indexing. This plate, however, is not, in indirect indexing, attached to the index-head spindle, but either or both the index plate and the indexing pin are geared to the spindle. Simple indexing is that form of indirect indexing in which the index plate is stationary and a single movement of the plate or the index crank is required for each spacing.

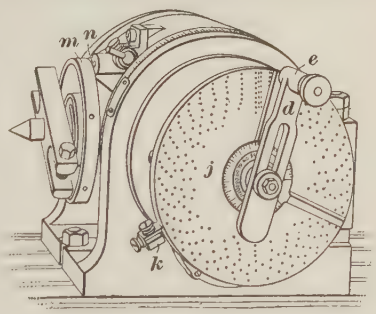


FIG. 2

One form of dividing head for simple indexing is shown in Fig. 2, and a cross-sectional view in Fig. 3. Corresponding parts in both illustrations have the same reference letters. The work spindle *a*, Fig. 3, carries a worm-gear *b* that meshes with a worm *c*. The crank *d* carrying the indexing, or latch, pin *e* is clamped on the end of the crank-shaft *f*, which drives the worm-shaft *g* by means of the equal spur gears *h* and *i*. The index plate *j* is attached to a hub that supports the crank-shaft *f*, and is held stationary by

the brake *k*, Fig. 2. The worm-gear *b* has forty teeth and the worm *c* a single thread.

6. The dividing head, Fig. 3, is also arranged for direct indexing. By giving the T-bolt *l* a half-turn the worm *c* is dropped from the worm-gear *b* and the spindle *a* is free to turn by hand. Then the front direct index plate *m*, Fig. 2, which is attached to the spindle *a*, Fig. 3, is used with the index pin *n* to space the work in the same manner as explained in connection with Fig. 1. The index plate *m*, Fig. 2, has three circles containing 24, 30, and 36 holes. By giving the T-bolt *l* a half-turn in the opposite direction and withdrawing and clamping

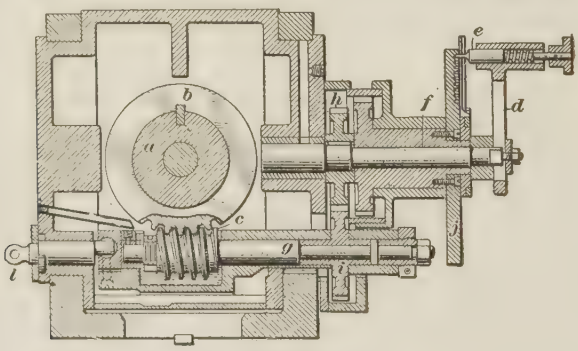


FIG. 3

the index pin *n* from the front plate *m*, the dividing head is arranged for indirect indexing.

7. Calculating Turns of Index Crank.—The part of a revolution made by the index-head spindle *a*, Fig. 3, for one complete turn of the worm-shaft *g* depends on the number of teeth on the worm-gear *b*, and whether the worm *c* has a single thread or a double thread. Index heads generally have single-threaded worms, and, for these, one turn of the worm will produce that part of a revolution of the index-head spindle represented by the fraction $\frac{1}{\text{number of teeth in worm-gear}}$. Suppose that the latch pin *e* engages the index circle having 20 holes, and that it is moved from one hole to the next adjoining

one. Then, the worm is rotated $\frac{1}{20}$ of a revolution; assuming the worm-gear to have 40 teeth, the index-head spindle is revolved $\frac{1}{40} \times \frac{1}{20} = \frac{1}{800}$ part of a revolution, and, hence, by making successive moves of 1 hole in the index circle having 20 holes, a circle is divided into $\frac{800}{1} = 800$ parts.

8. Now, suppose that, instead of moving the latch pin only 1 hole, it is moved 5 holes. Then, the worm-shaft makes $\frac{5}{20}$ of a revolution, the index-head spindle makes $\frac{1}{40} \times \frac{5}{20} = \frac{5}{800}$ of a turn, and hence a circle is divided into $\frac{800}{5} = 160$ parts. From the foregoing explanation the following rule is deduced:

Rule.—*To find the number of turns the index crank must make to space one of a desired number of equal divisions, divide the number of turns of the crank required for one revolution of the index-head spindle by the number of equal divisions desired.*

EXAMPLE.—In a certain make of index head, the crank must make 40 revolutions to produce 1 revolution of the index spindle. How many turns must the crank make to divide the circumference of the work into 6 equal parts?

SOLUTION.—Applying the rule, the number of turns of the index crank is

$$40 \div 6 = 6\frac{2}{3}. \quad \text{Ans.}$$

The index head usually has a 40-tooth worm-gear, though a 60-tooth gear is sometimes used. The number of teeth in the worm-gear on any index head, if a single-threaded worm is used, may be found by counting the number of turns of the crank required to give one complete turn of the spindle.

9. Selection of Index Circle.—Taking the example of Art. 8, it has been calculated that 6 whole turns and $\frac{2}{3}$ of a turn are required. The problem that now arises is how to measure $\frac{2}{3}$ of a turn of the crank by means of the index plate. For convenience of measuring different fractional parts of a turn, as $\frac{3}{5}$ of a turn, $\frac{5}{17}$ of a turn, $\frac{1}{19}$ of a turn, $\frac{2}{3}$ of a turn, etc., the index plate is provided with several concentric index circles, each circle having a different number of holes; several index plates with other circles of holes are provided to extend the range of the index head and increase the number of equal divisions obtainable. The limit of the method depends on the

plates and circles available. The index head shown in Fig. 2 is furnished with three index plates drilled with circles on both sides. With these all divisions up to 200, together with all even numbers and those divisible by 5 up to and including 400, may be made.

10. With the latch pin adjusted to the circle having twenty holes, to measure $\frac{2}{3}$ of a turn, the pin would have to be moved $20 \times \frac{2}{3} = 13\frac{1}{3}$ holes. But it would be impossible to judge accurately as to $\frac{1}{3}$ of the distance between two adjacent holes, and so an index circle is chosen that will enable the desired division to be obtained accurately. This is done by selecting a circle in which the number of holes is divisible, without a remainder, by the denominator of the fraction expressing the fractional part of a turn of the index crank. Suppose that the index circles have 20, 19, 18, 17, 16, and 15 holes; then there are two index circles divisible by the denominator 3 of the fractional part of a turn required in the above example, which are the 18-hole and 15-hole circles, either of which may be used.

11. Suppose the index circle having 15 holes is used. Then, to make $\frac{2}{3}$ of a turn, the latch pin must be moved $15 \times \frac{2}{3} = 10$ holes. If the circle having 18 holes is used, the latch pin must be moved $18 \times \frac{2}{3} = 12$ holes. From the foregoing statements, the following rule is obtained:

Rule.—*To measure fractional parts of a turn of the index crank, select an index circle having a number of holes that is exactly divisible by the denominator of the fraction when reduced to its lowest terms. Multiply the number of holes in the index circle thus selected by the fraction to obtain the number of holes that the latch pin must be moved for the fractional part of a turn.*

EXAMPLE.—In a given index head, 40 turns of the index crank will produce one turn of the index-head spindle. How many turns must the index crank make and what index circle would be used to divide the periphery of the work into 28 divisions? The index plate available has circles containing 37, 39, 41, 43, and 49 holes.

SOLUTION.—By the rule of Art. 8, the number of turns of the index crank is

$$40 \div 28 = 1\tfrac{12}{28} = 1\tfrac{3}{7}$$

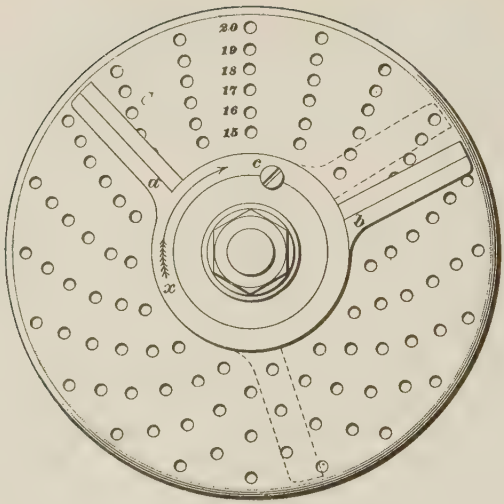
The denominator of the fraction $\frac{3}{7}$ is 7, and according to the foregoing rule, it is necessary to select a circle having a number of holes exactly divisible by 7. The only one of the five circles that can be used, therefore, is the 49-hole circle, as it is the only one that has a number of holes divisible by 7 without a remainder. Then, applying the latter part of the rule, the number of holes that the latch pin must be moved to produce $\frac{3}{7}$ of a turn is

$$49 \times \tfrac{3}{7} = 21$$

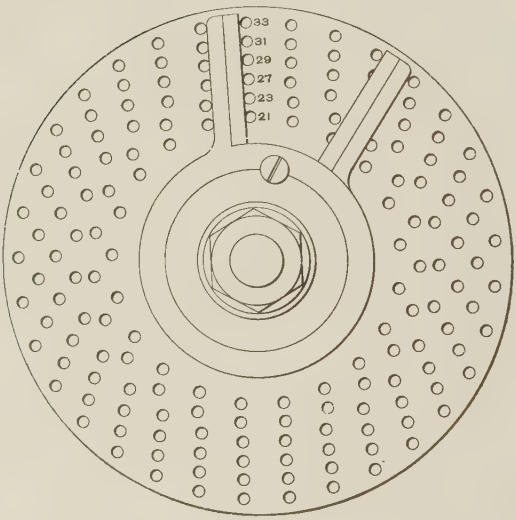
Therefore, to obtain 28 equal divisions, the 49-hole circle is used, and for each division the index crank is given one complete turn and 21 holes more. Ans.

12. Sector.—The **sector** is a spacing device used on the face of an index plate to save the labor of counting the number of holes for each move of the latch pin, and to prevent mistakes in counting. Fig. 4 (*a*) shows a sector in place on an index plate. It consists of two radial arms *a* and *b*, one on each of two circles that are jointed together so that the angle included between the arms can be changed; the two arms can be locked by tightening the clamp screw *c* to bind the two circles. To use the sector, the index crank is first adjusted so that the latch pin will drop into the numbered hole of the circle that has been selected. Suppose that the latch pin is adjusted to be used in the 18-hole circle, and that the sector is to be set to space 5 holes in this circle. The latch pin is dropped into a hole, as *d*, in the 18-hole circle, and the arm *a* is brought against the pin, as in the position shown. The arm *b* is then moved in the direction the index crank is to turn, which in this case is the direction of the arrow *x*, until the number of holes between the latch pin and the arm *b* is equal to the required number, or 5 in this instance. The arm *b* then occupies the position shown, and it is locked to the arm *a* by the clamp screw *c*. In setting the arms of the sector and counting off the desired number of holes to locate the arm *b*, the hole *d* in which the latch pin is inserted must *not* be counted; the required number of holes must appear *between* the latch pin and the arm *b*.

13. After the sector has been set as just described and the first cut has been taken, the latch pin is lifted from the starting hole *d*, Fig. 4 (*a*), and the index crank is given the required



(a)



(b)

FIG. 4

number of complete turns, taking the hole d as the starting point; then, to obtain the fractional part of a turn, the index crank is moved around until the latch pin can be dropped into the hole at the left edge of the arm b. As soon as this has been done, the arms are rotated in the direction of the arrow x, or in the same direction as the crank, until the arm a comes against the latch pin in its new position. The arms will then be in the

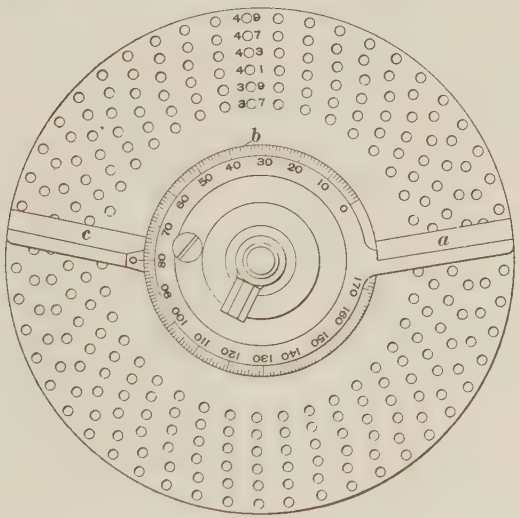


FIG. 5

positions indicated by the dotted lines, and will be set ready for the second spacing as soon as the second cut is taken.

14. It is customary in using the index head to keep the row of numbered holes in the index plate vertical, and to set the arms of the sector while the latch pin is in the numbered hole of the circle selected, instead of some other hole, as d. In ordinary indexing, the index crank may be moved either to the right or to the left, but the left-hand motion is generally used, as this turns the cut surface toward the workman and drops the cuttings at the front of the table. The arm b is then brought against the right side of the latch pin, leaving the vertical row of numbers uncovered. The arm a is moved to the

left the required number of holes and clamped. The sector is then set by moving the arms together to the left.

15. It is sometimes necessary to make slightly less than a whole turn of the index crank, as, for example, $\frac{30}{33}$ turn, and the arms of the sector cannot be moved far enough apart to include the thirty holes between them. The setting to space this would be made by giving the index crank a whole turn to the left to take up the backlash and entering the pin in the hole numbered *33*, Fig. 4 (*b*). The left-hand arm is then brought up to it. Thirty holes are next counted off to the left and the right-hand arm of the sector is brought up to the hole and the clamp screw is tightened. Indexing is done by pulling the pin out so far that it will clear the sector arms and rotating it to the left until the thirtieth hole just inside the sector arm is reached, where it is dropped in. The sector is then moved in the opposite direction, or to the right, and the machine is ready for the cut. If the workman prefers to turn the crank and move the sector in the opposite direction, it may be done.

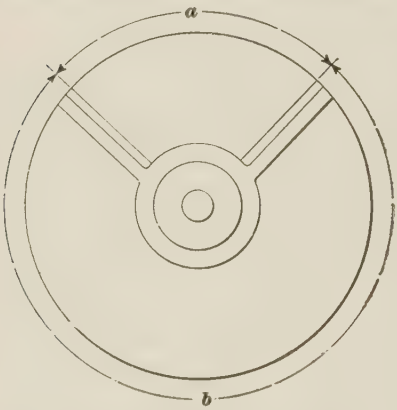


FIG. 6

16. Graduated Sector.—With the plain sector shown in Fig. 4 (*a*), it is necessary to count the holes in setting the arms. To avoid this work and also the liability of making an error in the count, the graduated sector shown in Fig. 5 has been devised. A portion of the outer edge of the circle to which the arm *a* is attached is marked with 172 equal divisions, as shown at *b*, and a zero line is marked on the arm *c*. Instead of counting the holes, bring the arm *c* against the latch pin and move the arm *a* until the zero on the arm *c* stands at the proper graduation on *b*. The graduation settings will be found in the fourth column of

Table I, given at the end of this Section. It is intended that Table I be used in connection with the graduated sector, as the makers have arranged the settings in the fourth column to correspond with the number of divisions of the work in the first column. For example, if six equal divisions are required, then the 18-, 33-, and 39-hole circles are available. If the 39-hole circle is used, $6\frac{26}{39}$ turns of the index crank are necessary, according to Table I and to get the fractional part of a turn, the arms

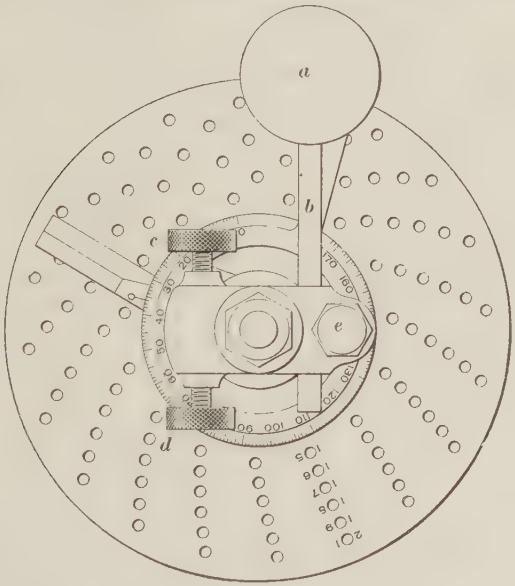


FIG. 7

of the graduated sector are set so that the zero on arm *c* is at 132 on the scale *b*, as 132 is the corresponding number given in the fourth column. If the number is not marked with a star (*), the latch pin is to be moved through the small arc *a*, Fig. 6, between the arms of the sector; but when the number is marked with a star, the latch pin is to be moved through the large arc *b*. The general explanation of Table I will be found under Differential Indexing.

17. Adjustable Index Crank.—For fine adjustments of the work it is found very convenient to have an adjustable

index crank, as shown in Fig. 7. This attachment enables the latch pin *a* to be located in any row of holes and brought to the nearest hole without disturbing the setting of the work. After the work is placed in position, the index plate is locked by the back stop-pin and the index crank *b* is adjusted, by turning the thumb screws *c* and *d*, until the latch pin enters the nearest hole. The crank may be moved, so as to bring the pin *a* in line with the selected circle, by loosening the clamp screw *e*. If it should be necessary to turn the work slightly relative to the index plate, the latch pin and the back stop-pin should both be engaged with the index plate, and then the screws *c* and *d* should be adjusted as required.

If the crank is not adjustable, as on the older machines, adjustments of less than one hole are made by the differential method, which requires the crankpin to be set in one row of holes and the back stop-pin in another row. The differential adjustment is made after the work has been set to the cutter by drawing out both stop-pins, which leaves the index plate free to turn in either direction. The plate is then turned until a hole in each circle coincides or lines with each pin. The pins are entered and indexing continued.

COMPOUND INDEXING

18. Principle of Operation.—The number of divisions obtainable by simple indexing is limited, the method depending on the number of available index circles and the number of holes in them. The range of divisions can, however, be greatly extended by compound indexing, which consists of two successive simple indexing operations, the result being either their sum or their difference. The principle of compound indexing may be explained as follows: Suppose that in Fig. 8, the latch pin *f* is adjusted to the 19-hole index circle, and the back stop-pin *h*, which is fitted to the frame of the index head, is adjusted to the 20-hole index circle; also, that the latch pin *f* is then withdrawn and the crank moved one hole, or $\frac{1}{19}$ of a turn, dropping the latch pin into the hole, and the back stop-pin *h* is next withdrawn from the index plate and the index plate

and crank together rotated one hole, or $\frac{1}{20}$ of a turn, in the same direction in which the index crank was first turned. Evidently, the worm c has been rotated $\frac{1}{19} + \frac{1}{20} = \frac{39}{380}$ of a turn, which is a part of a turn that ordinarily could not be measured without an index plate having a circle with 380 holes. Instead of the index plate being moved in the same direction as the index crank, the two together may be moved in the opposite direction. Then, the worm, as the result of the two

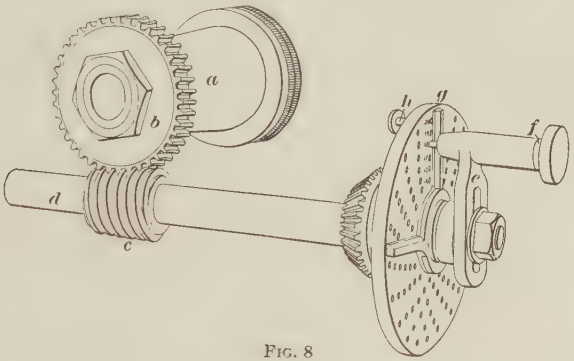


FIG. 8

movements, will have been rotated $\frac{1}{19} - \frac{1}{20} = \frac{1}{380}$ of a turn; this result, as before, could not ordinarily be measured with the index plate shown.

19. Calculation of Exact Compound Moves.—The moves required for compound indexing may be calculated by the following rule:

Rule.—*Factor the number of divisions it is desired to obtain. Choose an index plate and two circles of holes thereon for trial; take the difference of the number of holes in the two circles and factor this difference. Draw a horizontal line under all of these factors. Next, factor the number of turns of the index crank required for one turn of the index-head spindle and write the factors below the horizontal line. Factor the number of holes in the two chosen circles, and write the factors also below the line. Next, cancel equal factors above and below the line. If* **all** *factors above the line cancel, it is possible to obtain the proposed*

number of divisions by means of the two chosen circles. The number of holes to be gone forwards in one circle and backwards in the other circle is obtained by multiplying together the remaining factors below the line. Special attention is called to the fact that in case **all** *the factors* **above** *the line do not cancel out, two other circles must be tried until the desired result is obtained or the possible combinations have been exhausted. In case the division is feasible, write a plus sign before one move and a minus sign before the other move to signify that they are opposite in direction.*

EXAMPLE.—It is desired to obtain 91 divisions with an index head in which 40 turns of the crank produce 1 revolution of the index-head spindle. What are the moves that are required in case it is found that 91 divisions can be obtained by compound indexing?

SOLUTION.—Choose two circles for trial, as, for example, those having 21 and 31 holes. By the rule just given,

$$91 = 7 \times 13$$
$$31 - 21 = 10 = 2 \times 5$$
$$40 = 2 \times 2 \times 2 \times 5$$
$$31 = 31 \times 1$$
$$21 = 3 \times 7$$

It will be noticed that the factor 13 above the line does not cancel out; therefore, the proposed division cannot be obtained with circles having 31 and 21 holes. By trying different combinations, it will be found that circles having 39 and 49 holes will answer; thus,

$$91 = 7 \times 13$$
$$49 - 39 = 10 = 2 \times 5$$
$$40 \times 2 \times 2 \times 2 \times 5$$
$$49 = 7 \times 7$$
$$39 = 3 \times 13$$

It is seen that all the factors above the line cancel out. Multiplying the remaining factors below the line together, $2 \times 2 \times 7 \times 3 = 84$; that is, in order to obtain 91 divisions, it is necessary to go forwards 84 holes in the 49-hole circle, and backwards 84 holes in the 39-hole circle, or to go forwards 84 holes in the 39-hole circle and backwards 84 holes in the 49-hole circle. The moves written as directed in the rule are

$$+\tfrac{84}{49} - \tfrac{84}{39}, \text{ or } +\tfrac{84}{39} - \tfrac{84}{49}. \quad \text{Ans.}$$

20. Compound Index Table.—In compound indexing it is a great convenience to use a table giving the moves for any

number of divisions. Table II at the end of this Section was compiled for this purpose. The values in this table were first calculated by Mr. Walter Gribben and published in the American Machinist. Since then they have been used extensively by the Brown & Sharpe Company. The required information for compound indexing for from 51 to 250 divisions is given in Table II. The first column contains the number of divisions, those that can be spaced by simple indexing being omitted. The second column shows the circles to select and the moves of the crank to make at each indexing operation. The plus sign (+) indicates that both moves must be made in the same direction, and the minus sign (−) shows that the second move must be in the opposite direction from the first. Thus, according to the table, when indexing for 51 divisions, select the circles having 47 and 49 holes; make 8 turns and 41 holes in the 47-hole circle, and then move 12 holes in the opposite direction in the 49-hole circle for each indexing operation. The third column shows the total number of complete turns made by the work while indexing for all the desired divisions on it. In simple indexing, divisions that lie side by side are indexed and the work is completed in one turn; but with compound indexing it is generally necessary to index groups of divisions, and for this purpose more than one complete turn of the work is required. The reason for this fact is explained later. The required number of turns of the work corresponds to the number of divisions in each group that is indexed. Thus, from Table II, when indexing for 53 divisions, the work will be turned around 9 times and the groups indexed will contain 9 divisions each. The reason for this is shown in the following example:

21. Let it be required to index by the compound method for 53 divisions on a gear blank. Referring to Table II, it is seen in the second column that the moves for each indexing are 6 turns and 43 holes in the 47-hole circle, and 6 holes in the opposite direction in the 49-hole circle.

A diagram of the indexing operations is shown in Fig. 9. The first cut on the gear blank is taken at *a*. The indexing noted in the second column, $6\frac{4}{4}\frac{3}{7} - \frac{6}{4}\frac{}{9}$, is then performed and the

cut at *b* is taken. The second indexing sets the gear blank for the cut *c*, the third for the cut *d*, the fourth for the cut *e*, and the fifth for the cut *f*. The figure 9 in the third column shows that the indexing in Fig. 9 is for groups of 9 divisions. The fifth indexing, which locates the cut *f*, will therefore include $5 \times 9 = 45$ divisions. As the total number of divisions required on the work is 53, there are left in the last group, between *f* and *a*, $53 - 45 = 8$ divisions. Hence, the sixth indexing for 9 divisions will locate the gear blank so as to cut the space *g* at the right of *a* and finish the first tooth *h*. Continuing the indexing for groups of 9 divisions, the second time around the gear blank will locate the spaces *i*, *j*, *k*, *l*, *m*, and *n*, and complete the teeth *o*, *p*, *q*, *v*, *s*, and *t*. By repeating the operation, the entire 53 teeth will be made when the gear blank has been indexed through 9 complete turns.

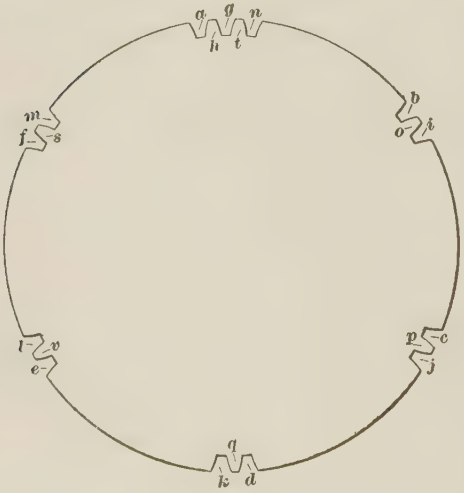


FIG. 9

22. Errors in Compound Indexing.—Where the work makes but one turn, as shown in the third column of Table II, in order to complete all the required divisions, the indexing is strictly accurate. When the index plates are not available to make single and consecutive divisions, and it becomes necessary to use compound indexing and to index for groups of divisions, the indexing is not strictly accurate. The error, however, is so small that it need not be considered in most cases.

23. The best plan to find the amount of error is by a trial indexing. Suppose that it is desired to calculate the error when

indexing for 63 divisions by the use of Table II. The move given in the table is $4\frac{19}{29}+\frac{14}{33}=\frac{4,861}{957}=5.0794148$. The move for perfect indexing for a group of 8 divisions, when the entire circumference of the work is to be divided into 63 divisions, and calculated by the rule of Art. **7**, should be $\frac{40}{63}\times 8=\frac{320}{63}=5.0793651$. The difference between the actual crank move given in the table and the required move is $5.0794148-5.0793651=.0000497$, which is the crank error when indexing the first group of 8 divisions. This crank error must be reduced to inches measured on the circumference of the work and the accumulated error on the last division found. The rule for making this calculation is as follows:

Rule.—*Multiply together the crank error in the first group, the length of the circumference of the work, and the total number of divisions, and divide the product by 40.*

Suppose that the work when indexing for 63 divisions is 1 inch in diameter, which is 3.1416 inches in circumference; then according to the rule the accumulated error when indexing the last of the 63 divisions will be $.0000497\times 3.1416\times 63\div 40=.0002459$ inch. As the required length of a division in this example should be $3.1416\div 63=.0498667$ inch, it will be seen that the error is approximately $\frac{1}{200}$ part of a division. In case the work is any other diameter than 1 inch, as given above, the error will be found by multiplying by the diameter.

DIFFERENTIAL INDEXING

24. Use of Spiral Head for Indexing.—The Brown & Sharpe Company have devised a method of indirect indexing, called **differential indexing,** which is carried out by the use of the spiral index head that they furnish. The advantages claimed for the method are that one circle of holes is used for each indexing, instead of two circles as in compound indexing; the index crank always turns in one direction; and it lessens the opportunity for error. The index-head spindle and the index plate are connected by a train of gearing, including certain

change gears, so that the index plate will turn either in the same direction as the crank or in the opposite direction, as may be required, and at the proper rate to locate a hole where the latch pin should stop. Change gears and index plates are regularly provided for making all divisions from 1 to 382. Additional gears and plates may be obtained for making more than 382 divisions. This index head may be used also for simple, or plain, indexing, and for compound indexing, as previously described.

25. Construction of Spiral Head.—The gearing used to connect the index plate with the spindle of the spiral head is shown in Fig. 10 (*a*) and (*b*). The index crank *a* carries a latch pin that may be dropped into any hole in the index plate *b*. The index plate is fastened to the miter gear *c* by screws, and the worm-shaft *d* passes through both. It is not keyed to the gear *c* but moves freely without moving either the gear or the index plate. A right-hand worm shown at *e* is keyed to the shaft and meshes with the spindle worm-gear *f*, which it operates. The worm-gear in this head has 40 teeth, so that by giving 40 turns to the index crank, which is adjustably secured to the worm-shaft, the worm-gear and index spindle rotate one complete turn.

26. On the outer end of the index spindle *g*, Fig. 10, is keyed the change gear *h*. The adjustable bracket *i* carries a bushing that is free to turn on the bracket stud, and to which are keyed the two change gears *j* and *k*. The second gear *j* on the stud meshes with the spindle gear *h*, and the first gear *k* on the stud meshes with the idler *l*, which is fastened to an adjustable bracket *p*. The adjustable bracket *i* is supported by a stud *r* located in what the makers call the *first hole*. The adjustable bracket *p* is supported by a stud *s* located in the *second hole*, which is below the first hole. These brackets may be used either singly or together. The idler serves merely to change the direction of motion of the gear *m*, and has no effect on the relative speeds of the gears. Keyed to the same shaft with the change gear *m* is a miter gear *n* that meshes with the miter gear *c*. These various gears are ordinarily known by

name. For example, the gear h is termed the gear on the spindle; the gear m is called the gear on the worm; and the gears j and k

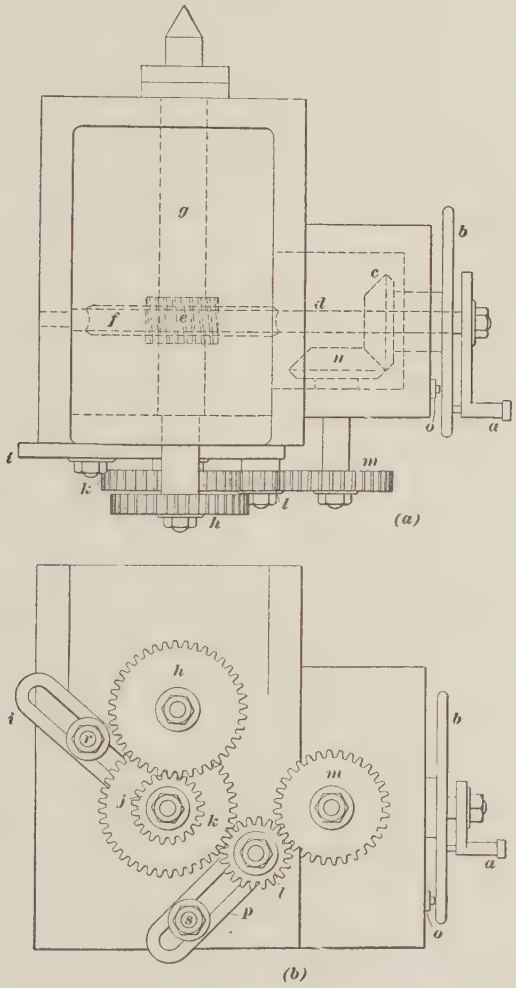


Fig. 10

are the gears on the stud. The gears on the stud are distinguished by stating the order in which they are put on the stud. In the illustration, the gear k must have been put on before the

gear *j*; therefore, the gear *k* is called the first gear on the stud and the gear *j* the second gear on the stud. The index plates furnished have 15, 16, 17, 18, 19, 20, 21, 23, 27, 29, 31, 33, 37, 39, 41, 43, 47, and 49 holes; and the change gears supplied are two 24-tooth gears and one each having 28, 32, 40, 44, 48, 56, 64, 72, 86, and 100 teeth.

27. Simple Indexing on Spiral Head.—When simple indexing is done on the spiral head, the gear train is disconnected and the back stop-pin *o*, Fig. 10, is slipped into a hole in the index plate to hold the plate in position. The back stop-pin slides in a hole in the frame of the index head close to the back of the index plate. Its purpose is to hold the index plate stationary when necessary, and it is used also as an indexing pin. In some designs the back stop-pin is so fixed that it engages but one row of holes in the back of the index plate. In other designs it is fitted to the frame of the index head so that it may be adjusted to engage any row of holes. When the index head is arranged as here described, simple indexing may be performed by turning the crank and plugging the latch pin into the holes that give the required spacing on the work.

28. Differential Indexing on Spiral Head.—When using the spiral head for differential indexing, the back stop-pin *o*, Fig. 10, is disengaged from the index plate *b* and the proper change gears and idlers put in mesh so as to give motion to the index plate from the index-head spindle. The principle of the differential method is as follows:

29. If the index plate shown in Fig. 11 is held stationary and the crankpin is withdrawn from the hole *a* and the crank is turned in the direction of the arrow *x*, then the crankpin will register with the hole *a* at each complete turn. If, on the other hand, the index plate is geared so that it turns while the crank turns, then the crank may move either a less or a greater amount than one complete turn in order that the crankpin may enter the hole *a*. Suppose, for example, that the gearing is arranged to move the index plate 1 complete turn in the same direction as the crank while the crank makes 40 turns; then the crankpin will pass the hole *a* only 39 times. If the index plate

moves in the opposite direction from the crank and at the rate of 1 turn for 40 turns of the crank, then the crankpin will register with the hole *a* 41 times for every 40 complete turns of the crank. Again, suppose that the index plate moves $2\frac{4}{5}$ times around in the opposite direction to the crank while the crank makes 40 complete turns. In this case the crankpin will pass the starting point *a* 42 times and go four-fifths further around the index plate. Now, if the 20-hole circle is used, a move of $\frac{4}{5} \times 20 = 16$ holes will be necessary in addition to the 42 times that the crankpin registers with the hole *a* in order to secure 40 actual turns of the crank.

30. Simple and Differential Index Table.—The makers of index heads furnish tables that give the divisions obtainable. Table I gives the data for simple and differential indexing by the use of the spiral index head. In the first column is given the number of equal divisions from 2 to 382. The second column contains the number of holes in the index-plate circle to be used. The third column shows the number of turns and fractions of a turn, if any, that the index crank must make on the index plate. The fractional part of a turn is usually given as a fraction whose denominator is the number of holes in the index circle that is to be used; the numerator denotes the number of holes of that circle that the latch pin is to be moved in addition to the whole turns. When no fractional part of a turn is required, any index circle may be used. The fourth column gives the setting of the graduated sector, previously explained; and the last six columns give the gears to be used, with their locations on the index head as designated in Fig. 10. If no number is given —that is, if the space is blank in a column—no

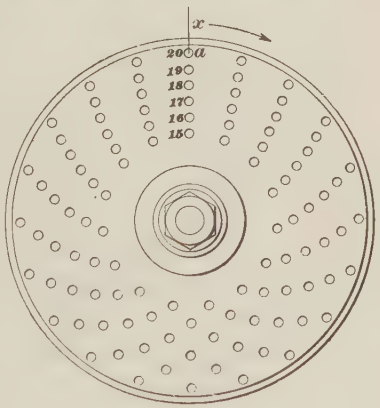


FIG. 11

gear is used in the position stated at the top of that column. The idlers referred to in the last two columns are put on the brackets *i* and *p*, the brackets being slotted and held by clamp screws so that the center distances between the gears are adjustable. The idler *k* in the ninth column goes on the arm *i* whose clamp screw *r*, according to the makers, enters what they call the first hole. The idler *l* in the tenth column goes on the bracket *p* whose clamp screw *s* enters what they call the second hole, which is the lower one in the frame of the index head. When there is no number in any of the last six columns, the indexing is simple, and the index plate remains stationary. When change gears must be used, the indexing is differential. The first gear on the stud, sixth column, is also designated as *k* because it is put on the bracket *i* when compound gearing, as in Fig. 10, is used. It will be noted in the table that the *idler k* is never used when the *gear k* is needed in compound gearing.

31. Calculations for Differential Indexing.—Table I should be used for differential indexing operations; otherwise, the calculations for ascertaining the crank moves, the circles, and the change gears are quite troublesome. When calculations become necessary, however, the following rules apply:

Rule I.—*To find the ratio of the change gears, multiply the number of holes in the circle selected by 40, and multiply the number of divisions to be indexed by the number of holes that the latch pin is to be moved at each indexing. Divide the difference between these two products by the number of holes in the index plate selected, and the quotient will be the ratio of the change gears to use.*

EXAMPLE 1.—What is the ratio of the change gears to use for connecting the index-head spindle to the index plate, when indexing for 271 divisions, and making a move of 3 holes in the 21-hole circle?

SOLUTION.—By applying rule I, the ratio of the change gears is

$$\frac{(21\times 40)-(271\times 3)}{21}=\frac{9}{7}. \quad \text{Ans.}$$

The numerator 9 represents the spindle gear *h*, Fig. 10, and the denominator 7, the gear *m*.

Rule II.—*To find the sizes of the change gears when their ratio is given, multiply both terms of the ratio by any number that*

will give values corresponding to the numbers of teeth on gears of practical sizes. These numbers should be sizes that can be selected from the gear set furnished with the index head.

EXAMPLE 2.—What pair of change gears should be used if their ratio is $\frac{9}{7}$?

SOLUTION.—Applying rule II, $\frac{9}{7}\times\frac{8}{8}=\frac{72}{56}$. Referring to the gear set in Art. **25**, it is seen that 72 and 56 are the gears that are multiples of 9 and 7,

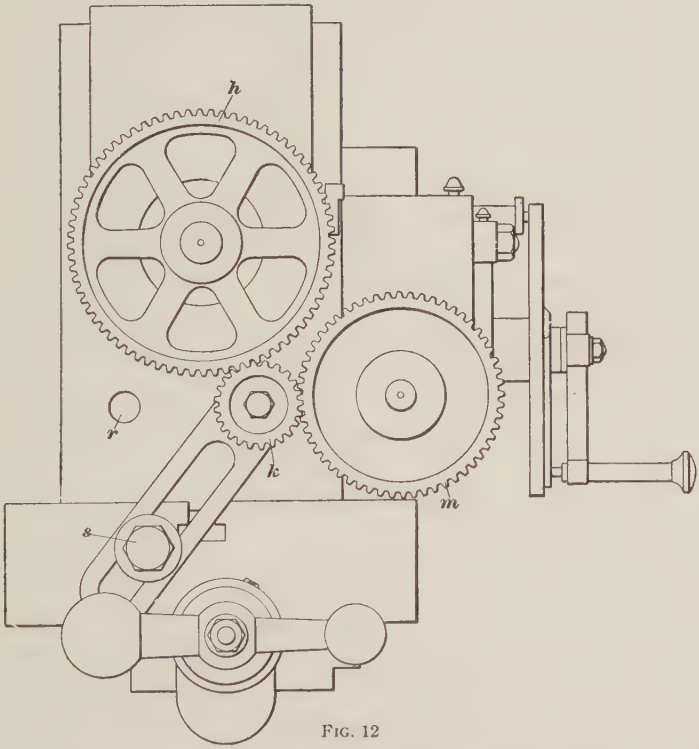


FIG. 12

the numerator and the denominator of the ratio, respectively. Then, the gear having 72 teeth should be placed at *h*, Fig. 12, and the gear having 56 teeth at *m*. Ans.

An idler *k* having 24 teeth will close the train. These are the gears given in the eighth, fifth, and ninth columns of Table I. The values assumed for the circle and the move in the foregoing calculations are those given in the table.

32. The values for the circle and the latch-pin move must be assumed, and a calculation made. If change gears of practical sizes are not obtained, other values must be assumed for the circle and the move, the calculation repeated, and the process continued until a suitable gear ratio is obtained. A move of 3 holes was assumed in the foregoing calculation in order to make the second product in the numerator as nearly equal as possible to the first product, and thus lower the gear ratio. As considerable effort is required to turn the index crank when a large gear is on the spindle, the makers recommend that this ratio should not exceed 6 to 1. When the ratio is too large for a single pair of gears, called *simple gearing*, then two pairs, or compound gears, must be used.

Rule.—*To find the compound gears when the gear ratio of the change gears is known, separate the ratio into two fractions and treat each of these fractions the same as when ascertaining a single pair of gears for simple gearing.*

EXAMPLE.—Find the gears when indexing for 319 divisions, using the 29-hole circle and a move of 4 holes.

SOLUTION.—Applying the rule for the ratio,

$$\frac{(319\times 4)-(29\times 40)}{29}=\frac{4}{1}$$

As no change gear furnished in the set has four times as many teeth as another, compound gearing must be used. It is seen that $\frac{4}{1}=\frac{3}{1}\times\frac{4}{3}$; also, by the rule for simple gearing, $\frac{3}{1}\times\frac{24}{24}=\frac{72}{24}$, and $\frac{4}{3}\times\frac{16}{16}=\frac{64}{48}$. Such gears as 72, 24, 64, and 48 are regularly furnished. In compound gearing, as in simple gearing by this rule, the numerators represent the drivers and the denominators the driven gears; therefore, the 72-tooth gear will be located at *h*, Fig. 10, the 64-tooth gear at *k*, the 24-tooth gear at *j*, and the 48-tooth gear at *m*. Ans.

33. Differential Indexing for High Divisions.—Occasionally it becomes necessary to index for a greater number of divisions than are given in Table I. In these cases the same method of calculation should be followed as already explained, when using the data given in the table. Thus, suppose that it

is required to index a circle for $\frac{1}{4}°$, or $4\times360=1{,}440$ divisions. As a trial calculation, assume the use of the 33-hole circle and a move of 1 hole at a time; then,

$$\frac{(1{,}440\times1)-(33\times40)}{33}=\frac{40}{11}$$

The change gears in the set, Art. **26,** do not show any two gears with 40 and 11 teeth or equal multiples of the same, and so compound gearing must be used. It will be seen that $\frac{40}{11}=\frac{25}{11}\times\frac{8}{5}$; $\frac{25}{11}\times\frac{4}{4}=\frac{100}{44}$, and $\frac{8}{5}\times\frac{8}{8}=\frac{64}{40}$. The drivers, 100 and 64, are located at *h* and *k*, Fig. 10, respectively, and the followers, 44 and 40, at *j* and *m*.

34. Fractional Spacing.—In some cases it may be necessary to use fractional spacing. One example of this kind is the marking of $\frac{1}{12}°$ divisions on an arc used as a vernier for measuring 5′, or $\frac{1}{12}°$. In this case the length of the divisions is such that for the entire circle there would be $360\div\frac{1}{12}=360\times\frac{12}{11}=392\frac{8}{11}$ equal divisions. The calculation is precisely the same as when whole numbers are used. The use of some circle and move is assumed, and rule I, Art. **31,** is applied. Thus, suppose that the 18-hole circle is used and a move of 2 holes made; then,

$$\frac{(392\frac{8}{11}\times2)-(18\times40)}{18}=\frac{785\frac{5}{11}-720}{18}=\frac{65\frac{5}{11}}{18}=\frac{720}{11}\times\frac{1}{18}=\frac{40}{11}$$

As this fraction, $\frac{40}{11}$, is the same as the ratio of the gears required in the example of Art. **33,** the same gears may be used.

35. Simple Indexing and Differential Indexing Compared.—The values for the crank moves in the third column of Table I for all simple indexing operations are equal to 40 divided by the corresponding number of divisions in the first column. In this case the actual turns of the crank and the number of turns as shown on the index plate are the same, for the reason that no gearing is used and the index plate is stationary. In differential indexing, the index plate moves, and the actual crank turns and the crank turns as indicated on the moving index plate are not the same. To get the values in

the third column, which are the crank turns as indicated on the index plate for differential indexing, the actual required turns of the crank must be increased or decreased by an amount equal to the move made by the index plate in each case. Thus, suppose that indexing for 51 divisions is desired and that the 17-hole circle is selected. The actual move of the crank is $\frac{40}{51}$, and the move on the index plate if stationary would be $\frac{40}{51} \times 17 = 13\frac{1}{3}$ spaces on the 17-hole circle. Now, if the index plate is geared so that it will move $\frac{2}{3}$ of a space in the 17-hole circle in the opposite direction from the crank while the crank makes the required $\frac{40}{51}$ turn, then the crankpin will drop into the fourteenth hole, because $13\frac{1}{3} + \frac{2}{3} = 14$. Therefore, the crank move as indicated on the moving index plate, and as given in the third column, is $13\frac{1}{3} + \frac{2}{3} = 14$ holes, and the gearing to move the plate two-thirds of a space on the 17-hole circle while the crank makes $\frac{40}{51}$ turn is found as follows: For each $\frac{40}{51}$ turn of the crank the spindle, or work, makes $\frac{40}{51} \times \frac{1}{40} = \frac{1}{51}$ turn; also for each $\frac{40}{51}$ turn of the crank the index plate must make $\frac{2}{3} \times \frac{1}{17} = \frac{2}{51}$ turn. As the index plate makes $\frac{2}{51}$ turn while the spindle makes $\frac{1}{51}$ turn, it follows that the index plate turns twice as fast as the spindle. Therefore, any pair of change gears in which one is twice the size of the other may be used, and the larger one must be the driver and be located on the spindle at *h*, Fig. 10. The pair of gears given in Table I have 48 and 24 teeth.

36. Use of Idlers.—The train of gears used in differential indexing on the index heads shown in Figs. 10 and 12 may have to include one or two idlers, or no idler at all, to obtain the correct direction of rotation of the index plate. The train of gearing between the spindle and the index plate is so arranged that the idlers have the following effect: With simple gearing the index plate will turn in the opposite direction from the crank either with no idler or with two idlers in use; with one idler the index plate will turn in the same direction. With compound gearing the index plate will turn in the same direction as the crank with no idler, and in the opposite direction from the crank when one idler is used. An inspection of Table I shows that two idlers are never used with compound gearing.

37. Hendey Differential Indexing.—The Hendey index head differs from that illustrated in Fig. 10, because a pair of spiral gears are used in place of the miter gears *c* and *n*. These miter gears are of the same size, and consequently the index plate *b* and the gear *m* turn at the same rate. In the Hendey head, however, the spiral gears are unequal in size, and the one that replaces the miter gear *c* has just twice as many teeth as the one that replaces the miter gear *n*. The result is that the Hendey index plate, if geared from Table I, will make half as many turns per revolution of the index spindle, as in the heads shown in Figs. 10 and 12. Therefore, if the same index-plate circle is used, and the latch pin is moved the same number of holes, to get a desired spacing as with the Brown & Sharpe index head, the gear on the worm in the Hendey head must have half as many teeth as the gear *m*, Figs. 10 and 12, or a corresponding alteration must be made in other gears of the train. Otherwise, the method of calculating the change gears is the same for both index heads.

LINEAR INDEXING

38. Feed-Screws of Milling Machine.—The ordinary universal milling machine has three feed-screws. One moves the table lengthwise, another moves the saddle crosswise, and the third moves the knee and the table vertically. These screws are fitted with graduated dials and thus may be used for linear indexing. The feed-screw for the lengthwise motion ordinarily has 4 threads per inch, and its dial is graduated into 250 equal divisions; therefore, a movement of one division causes the table to move lengthwise .001 inch, and one complete turn moves it $\frac{1}{4}$ inch. The cross-feed screw has 8 threads per inch and a dial graduated into 125 equal parts; hence, a movement of one division causes the saddle to move crosswise .001 inch. The knee is raised by a screw having 4 threads per inch and fitted with a bevel gear that has $2\frac{1}{2}$ times as many teeth as the gear on the feed-shaft leading to the front of the knee. The feed-shaft has a dial graduated into 100 equal divisions, and so, for each division moved, the knee is raised .001 inch.

39. Backlash, or Lost Motion.—When a screw is required to work easily in a nut, the thread on the screw is made somewhat narrower than the space between threads in the corresponding nut. This looseness or play between the two parts is called *backlash*, or *lost motion*. The amount of original backlash required to secure easy movement of a screw in a nut is increased by wear, making it necessary in some cases to renew one or both of the parts or to provide some method by which the looseness can be taken up. The effect of backlash between a feed-screw and its nut is that when the screw is turned backwards, after turning it in one direction, it will make a part of a turn without giving any motion to the part it is intended to move. Therefore, the backlash should be allowed for when using the feed-screws. This is best done by moving the nut farther with the reverse turns of the screw than necessary, then turning the screw in the same direction as for previous settings and moving the work to its correct position. In other words, all settings are made by turning the screw in the *same* direction. This direction should be such as to resist the greatest weight, such as upwards, for example, when setting the knee of a milling machine.

40. Spacing Jig Holes on Milling Machine.—The method of linear indexing may be shown by the spacing of the holes in a jig such as that shown in Fig. 13. The jig body is first planed accurately to the required size, and is then secured to the milling-machine table, with the face *a* on the table and the face *b* toward the spindle of the machine. It is brought in line with the table by being forced in against a parallel strip or an angle plate and is then tested for accuracy of setting. The alinement should be such that at each end a strip of paper will be held with the same pressure between the tool and the work. The positions of the several holes are laid off from the edges *c* and *d*, on the face *b*.

41. A sharp-pointed center is placed in the milling-machine spindle and the jig fed lengthwise toward the center, so as to take up all backlash in the screw, and until the starting end *c*, Fig. 13, is exactly in line with the point of the center. The index

pointer on the lengthwise feed-screw is then set to zero on the dial and the table is clamped or held by stops, which may be used to gauge from. The feed-screw is now given 4 complete turns and 125 divisions, which moves the work 1.125 inches and brings the center of the spindle in line with the vertical center line of the hole *e*. The knee is next lowered until the top edge is about $\frac{1}{2}$ inch below the center of the spindle and is then raised carefully, to take up the backlash, until the top edge is exactly level with the center and gauges the right distance above the working sur-

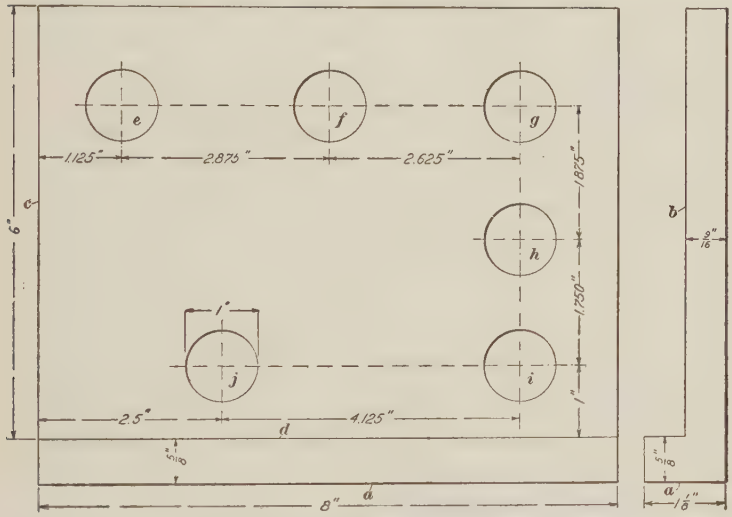


FIG. 13

face *d*. The dial on the knee screw is then set to zero and the screw is turned 13 times and 75 divisions more, thus raising the top edge 1.375 inches and bringing the center of the hole *e* opposite the point of the center in the spindle. The table is clamped in this position, the center is replaced by a short, stiff drill, and the hole is drilled $\frac{1}{16}$ inch under size, the cross-feed being used to feed the work against the drill. The drill is replaced by a boring tool and the hole is bored true, a sufficient allowance being left for reaming to finish the hole.

42. The setting of the work to drill the hole *f*, Fig. 13, is simple. The horizontal center line is already in line with the

center of the spindle; so the table is unclamped and the lengthwise feed-screw is given 11 turns and 125 divisions more, thus moving the table 2.875 inches and bringing the center of the hole *f* opposite the center of the spindle. The table is clamped in this position and the hole *f* is drilled, and finished like the first, after which it is unclamped and moved 2.625 inches farther by giving the feed-screw 10 turns and 125 divisions. This brings the hole *g* in proper position for drilling. When it has been drilled and finished, the knee is raised vertically 1.875 inches, by turning the screw 18 times and 75 divisions more, and is clamped while the hole *h* is drilled. It is then unclamped and raised 1.750 inches more, to allow the hole *i* to be drilled and finished. The center distances of the holes *g*, *h*, and *i* should be checked by gauging from the starting edge *c* or the stop, as errors are liable to be introduced by the vertical movement of the knee.

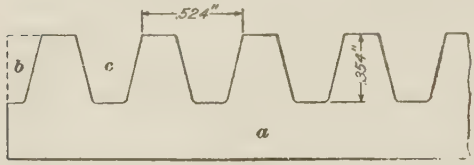


FIG. 14

43. After drilling the hole *i*, Fig. 13, the table must be returned lengthwise to drill the hole *j*. Because of backlash, it would not be accurate to turn the screw 16 turns and 125 divisions in the reverse direction, to space the hole *j* at a distance of 4.125 inches from the hole *i*. Instead, the table is run back until the edge *c* is $\frac{1}{2}$ inch or so beyond the center of the spindle. The table is then brought forwards until it is in line with the center, as at the beginning. All backlash should be thus taken up and the pointer should again stand at zero on the dial. If it does, the screw is given 10 turns, to move the table 2.5 inches, and the last hole *j* is drilled.

44. Spacing Rack Teeth on Milling Machine.—Suppose that a rack having teeth of the size shown in Fig. 14 is to be cut on the milling machine. The pitch or distance from center to center of adjacent teeth, or from the edge of one to the corresponding edge of the next, is .524 inch, which indicates that the rack must be moved a distance of .524 inch after each

space is cut. The bar *a* in which the rack is to be cut is clamped in a vise that is set square with the table. A parallel is put beneath it, so that the bottoms of the spaces between the teeth will be above the tops of the jaws. The proper cutter is clamped on the arbor and the blank is run under the cutter and raised until the revolving cutter just touches its top face. The cross-feed is now used to run it out from the column until the inner end is some distance beyond the cutter, after which the feed-screw is turned in the other direction to take up all backlash, and so far that the cutter will cut about half a space at the end, as shown at *b*.

45. The cutter must next be set to cut to the proper depth, which is .354 inch, according to Fig. 14. To do this, the pointer on the dial of the knee feed-screw is set at zero and the screw is then turned 3 complete turns and 54 graduations additional, raising the work .3+.054=.354 inch. The knee is then clamped in position, and the pointer on the dial of the cross-feed screw is set at zero. The work is now fed under the cutter by using the lengthwise feed-screw, and the half-space *b* is cut. The work is then moved .524 inch toward the column by turning the cross-feed screw 4 times and 24 divisions past the pointer, and the space *c* is cut. These operations are repeated until the rack is completed.

46. Care in Indexing.—An unbalanced crank should never be left on any feed-screw used for indexing, while a cut is being made. As soon as the indexing movement is complete, the crank should be removed until it is required for the next movement. If the crank is left on the screw it is liable to move back and introduce backlash, which will prevent accurate indexing. If, in making any index movement, the pin or pointer should accidentally be moved past the hole or line where it should stop, the crank should be given at least half a turn backwards and then should be moved forwards to take up the backlash, after which the pin should be dropped into the hole or the pointer set opposite the required graduation line. It is always necessary when doing any cutting to keep all parts of

the machine clamped as securely as possible and not to make any indexing movement until the proper clamp is loosened.

47. Whenever it is possible to do so, the index pointer should be kept tightened from the start to the finish of a job of linear indexing. If however, the number of divisions to be moved at each indexing is unusual and hard to count, the pointer may be reset for each movement. Thus, suppose that 67 divisions must be moved at each spacing. The pointer is first set to zero and then is turned to the 67 mark on the dial for the first spacing. This graduation is marked with chalk or pencil, and when the cut is finished the pointer is returned to the zero and reclamped. The second indexing is then made to the same graduation mark as before, and the second cut is taken. This operation is repeated as often as may be necessary. Before any cut except the first has been made, index once around the work or across its full length, and make a light mark with the tool at every second indexing. By counting these marks it may be determined whether the correct number of divisions will be made. Having thus made certain that the indexing is correct, the work may be proceeded with. The marks made at the first indexing will then show any slipping of the work or any error in indexing while proceeding with the work.

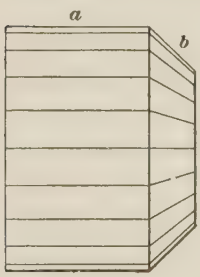


FIG. 15

48. Effect of Changing Inclination of Index-Head Spindle.—When the angle of the index spindle is changed while work is held in the chuck or the spindle, it will be found that the spindle is rotated slightly. By the act of changing the angle the worm-wheel is moved a short distance around the worm, which causes the worm-wheel to turn slightly on its axis. After each change of the angle of the index head the work must be reset by rotating it in the required direction by means of the index crank. For example, suppose that it is required to cut teeth on the plain part *a* of the cutter shown in Fig. 15; and to continue them down the inclined part *b*. The index head is

set to zero and the plain part *a* is cut. The head is then elevated to the required angle, after which it will be found that the index has changed so that the cutter will no longer enter the spaces at *a* without cutting a little from one side or the other. Both the back stop-pin and the latch pin are then withdrawn from the plate and the work is revolved so that the cutter enters a slot without cutting either side. The index plate is then revolved until both pins enter holes in the plate, and the cutting is resumed.

49. Drilling Index Plates.—If it is desired to drill an index plate, the plate is fastened on an arbor fitting the index-head spindle. The head is put on the raising block and set at right angles to the table, and a drill chuck is put in the machine spindle. A short, stiff, flat starting drill is then gripped in the chuck and the head is adjusted so that the circle will be properly located on the plate. If a number of rows of holes are to be drilled the starting holes should be in a radial line. This may be provided for by setting the axis of the index spindle at the same height as the axis of the cutter spindle and feeding the table horizontally the required distance between any two circles. It can also be done by setting the axis of the index spindle directly below the axis of the main spindle, drilling the outer row of holes first and raising the knee the required distance to drill each succeeding smaller circle. If a flat starting drill is used, the holes are first spotted by speeding up the drill and feeding the plate to the drill by the cross-feed after each indexing. The flat starting drill is then replaced by a twist drill and the holes are drilled to size and depth. A twist drill may be used and the holes drilled at one operation; but this is usually less accurate than the flat-drill method.

TABLE I

SIMPLE AND DIFFERENTIAL INDEXING

Number of Divisions	Index Circle	Number of Turns of Crank	Graduated Sector Divisions	Gear on Worm *m*	First Gear on Stud *k*	Second Gear on Stud *j*	Gear on Spindle *h*	Idlers	
								First Hole *k*	Second Hole *l*
2	Any	20							
3	39	$13\frac{13}{39}$	65						
4	Any	10							
5	Any	8							
6	39	$6\frac{26}{39}$	132						
7	49	$5\frac{35}{49}$	140						
8	Any	5							
9	27	$4\frac{12}{27}$	88						
10	Any	4							
11	33	$3\frac{21}{33}$	126						
12	39	$3\frac{13}{39}$	65						
13	39	$3\frac{3}{39}$	14						
14	49	$2\frac{42}{49}$	169						
15	39	$2\frac{26}{39}$	132						
16	20	$2\frac{10}{20}$	98						
17	17	$2\frac{6}{17}$	69						
18	27	$2\frac{6}{27}$	43						
19	19	$2\frac{2}{19}$	19						
20	Any	2							
21	21	$1\frac{19}{21}$	18*						
22	33	$1\frac{27}{33}$	161						
23	23	$1\frac{17}{23}$	147						
24	39	$1\frac{26}{39}$	132						
25	20	$1\frac{12}{20}$	118						
26	39	$1\frac{21}{39}$	106						
27	27	$1\frac{13}{27}$	95						
28	49	$1\frac{21}{49}$	83						
29	29	$1\frac{11}{29}$	75						
30	39	$1\frac{13}{39}$	65						
31	31	$1\frac{9}{31}$	56						
32	20	$1\frac{5}{20}$	48						
33	33	$1\frac{7}{33}$	41						
34	17	$1\frac{3}{17}$	33						
35	49	$1\frac{7}{49}$	26						
36	27	$1\frac{3}{27}$	21						
37	37	$1\frac{3}{37}$	15						
38	19	$1\frac{1}{19}$	9						
39	39	$1\frac{1}{39}$	3						
40	Any	1							
41	41	$\frac{40}{41}$	3*						
42	21	$\frac{20}{21}$	9*						
43	43	$\frac{40}{43}$	12*						
44	33	$\frac{30}{33}$	17*						
45	27	$\frac{24}{27}$	21*						
46	23	$\frac{20}{23}$	172						
47	47	$\frac{40}{47}$	168						

TABLE I—(*Continued*)

Number of Divisions	Index Circle	Number of Turns of Crank	Graduated Sector Divisions	Gear on Worm *m*	First Gear on Stud *k*	Second Gear on Stud *j*	Gear on Spindle *h*	Idlers	
								First Hole *k*	Second Hole *l*
48	18	$\frac{15}{18}$	165						
49	49	$\frac{40}{49}$	161						
50	20	$\frac{16}{20}$	158						
51	17	$\frac{14}{17}$	33*	24			48	24	44
52	39	$\frac{30}{39}$	152						
53	49	$\frac{35}{49}$	140	56	40	24	72		
54	27	$\frac{20}{27}$	147						
55	33	$\frac{24}{33}$	144						
56	49	$\frac{35}{49}$	140						
57	21	$\frac{15}{21}$	140	56			40	24	44
58	29	$\frac{20}{29}$	136						
59	39	$\frac{28}{39}$	132	48			32	44	
60	39	$\frac{26}{39}$	132						
61	39	$\frac{28}{39}$	132	48			32	24	44
62	31	$\frac{20}{31}$	127						
63	39	$\frac{26}{39}$	132	24			48	24	44
64	16	$\frac{10}{16}$	123						
65	39	$\frac{24}{39}$	121						
66	33	$\frac{20}{33}$	120						
67	21	$\frac{12}{21}$	113	28			48	44	
68	17	$\frac{10}{17}$	116						
69	20	$\frac{12}{20}$	118	40			56	24	44
70	49	$\frac{28}{49}$	112						
71	18	$\frac{10}{18}$	109	72			40	24	
72	27	$\frac{16}{27}$	110						
73	21	$\frac{12}{21}$	113	28			48	24	44
74	37	$\frac{20}{37}$	107						
75	15	$\frac{8}{15}$	105						
76	19	$\frac{10}{19}$	103						
77	20	$\frac{10}{20}$	98	32			48	44	
78	39	$\frac{20}{39}$	101						
79	20	$\frac{10}{20}$	98	48			24	44	
80	20	$\frac{10}{20}$	98						
81	20	$\frac{10}{20}$	98	48			24	24	44
82	41	$\frac{20}{41}$	96						
83	20	$\frac{10}{20}$	98	32			48	24	44
84	21	$\frac{10}{21}$	94						
85	17	$\frac{8}{17}$	92						
86	43	$\frac{20}{43}$	91						
87	15	$\frac{7}{15}$	92	40			24	24	44
88	33	$\frac{15}{33}$	89						
89	18	$\frac{8}{18}$	87	72			32	44	
90	27	$\frac{12}{27}$	88						
91	39	$\frac{18}{39}$	91	24			48	24	44
92	23	$\frac{10}{23}$	86						
93	18	$\frac{8}{18}$	87	24			32	24	44
94	47	$\frac{20}{47}$	83						
95	19	$\frac{8}{19}$	82						

TABLE I—(*Continued*)

Number of Divisions	Index Circle	Number of Turns of Crank	Graduated Sector Divisions	Gear on Worm *m*	First Gear on Stud *k*	Second Gear on Stud *j*	Gear on Spindle *h*	Idlers	
								First Hole *k*	Second Hole *l*
96	21	$\frac{9}{21}$	85	28			32	24	44
97	20	$\frac{8}{20}$	78	40			48	44	
98	49	$\frac{20}{49}$	79						
99	20	$\frac{8}{20}$	78	56	28	40	32		
100	20	$\frac{8}{20}$	78						
101	20	$\frac{8}{20}$	78	72	24	40	48		24
102	20	$\frac{8}{20}$	78	40			32	24	44
103	20	$\frac{8}{20}$	78	40			48	24	44
104	39	$\frac{15}{39}$	75						
105	21	$\frac{9}{21}$	75						
106	43	$\frac{16}{43}$	73	86	24	24	48		
107	20	$\frac{8}{20}$	78	40	56	32	64		24
108	27	$\frac{10}{27}$	73						
109	16	$\frac{6}{16}$	73	32			28	24	44
110	33	$\frac{12}{33}$	71						
111	39	$\frac{13}{39}$	65	24			72	32	
112	39	$\frac{13}{39}$	65	24			64	44	
113	39	$\frac{13}{39}$	65	24			56	44	
114	39	$\frac{13}{39}$	65	24			48	44	
115	23	$\frac{8}{23}$	68						
116	29	$\frac{10}{29}$	68						
117	39	$\frac{13}{39}$	65	24			24	56	
118	39	$\frac{13}{39}$	65	48			32	44	
119	39	$\frac{13}{39}$	65	72			24	44	
120	39	$\frac{13}{39}$	65						
121	39	$\frac{13}{39}$	65	72			24	24	44
122	39	$\frac{13}{39}$	65	48			32	24	44
123	39	$\frac{13}{39}$	65	24			24	24	44
124	31	$\frac{10}{31}$	63						
125	39	$\frac{13}{39}$	65	24			40	24	44
126	39	$\frac{13}{39}$	65	24			48	24	44
127	39	$\frac{13}{39}$	65	24			56	24	44
128	16	$\frac{5}{16}$	61						
129	39	$\frac{13}{39}$	65	24			72	24	44
130	39	$\frac{13}{39}$	60						
131	20	$\frac{6}{20}$	58	40			28	44	
132	33	$\frac{10}{33}$	59						
133	21	$\frac{6}{21}$	56	24			48	44	
134	21	$\frac{6}{21}$	56	28			48	44	
135	27	$\frac{8}{27}$	58						
136	17	$\frac{5}{17}$	57						
137	21	$\frac{6}{21}$	56	28			24	56	
138	21	$\frac{6}{21}$	56	56			32	44	
139	21	$\frac{6}{21}$	56	56	32	48	24		
140	49	$\frac{14}{49}$	55						
141	18	$\frac{5}{18}$	54	48			40	44	
142	21	$\frac{6}{21}$	56	56			32	24	44
143	21	$\frac{6}{21}$	56	28			24	24	44

TABLE I—(*Continued*)

Number of Divisions	Index Circle	Number of Turns of Crank	Graduated Sector Divisions	Gear on Worm *m*	First Gear on Stud *k*	Second Gear on Stud *j*	Gear on Spindle *h*	Idlers	
								First Hole *k*	Second Hole *l*
144	18	$\frac{5}{18}$	54						
145	29	$\frac{8}{29}$	54						
146	21	$\frac{8}{21}$	56	28			48	24	44
147	21	$\frac{6}{21}$	56	24			48	24	44
148	37	$\frac{10}{37}$	53						
149	21	$\frac{6}{21}$	56	28			72	24	44
150	15	$\frac{4}{15}$	52						
151	20	$\frac{5}{20}$	48	32			72	44	
152	19	$\frac{5}{19}$	51						
153	20	$\frac{5}{20}$	48	32			56	44	
154	20	$\frac{5}{20}$	48	32			48	44	
155	31	$\frac{8}{31}$	50						
156	39	$\frac{10}{39}$	50						
157	20	$\frac{5}{20}$	48	32			24	56	
158	20	$\frac{5}{20}$	48	48			24	44	
159	20	$\frac{5}{20}$	48	64	32	56	28		
160	20	$\frac{5}{20}$	48						
161	20	$\frac{5}{20}$	48	64	32	56	28		24
162	20	$\frac{5}{20}$	48	48			24	24	44
163	20	$\frac{5}{20}$	48	32			24	24	44
164	41	$\frac{10}{41}$	47						
165	33	$\frac{5}{33}$	47						
166	20	$\frac{5}{20}$	48	32			48	24	44
167	20	$\frac{5}{20}$	48	32			56	24	44
168	21	$\frac{5}{21}$	47						
169	20	$\frac{5}{20}$	48	32			72	24	44
170	17	$\frac{4}{17}$	45						
171	21	$\frac{5}{21}$	47	56			40	24	44
172	43	$\frac{10}{43}$	44						
173	18	$\frac{4}{18}$	43	72	56	32	64		
174	18	$\frac{4}{18}$	43	24			32	56	
175	18	$\frac{4}{18}$	43	72	40	32	64		
176	18	$\frac{4}{18}$	43	72	24	24	64		
177	18	$\frac{4}{18}$	43	72			48	24	
178	18	$\frac{4}{18}$	43	72			32	44	
179	18	$\frac{4}{18}$	43	72	24	48	32		
180	18	$\frac{4}{18}$	43						
181	18	$\frac{4}{18}$	43	72	24	48	32		24
182	18	$\frac{4}{18}$	43	72			32	24	44
183	18	$\frac{4}{18}$	43	48			32	24	44
184	23	$\frac{5}{23}$	42						
185	37	$\frac{8}{37}$	42						
186	18	$\frac{4}{18}$	43	48			64	24	44
187	18	$\frac{4}{18}$	43	72	48	24	56		24
188	47	$\frac{10}{47}$	40						
189	18	$\frac{4}{18}$	43	32			64	24	44
190	19	$\frac{4}{19}$	40						
191	20	$\frac{4}{20}$	38	40			72	24	

TABLE I—(*Continued*)

Number of Divisions	Index Circle	Number of Turns of Crank	Graduated Sector Divisions	Gear on Worm *m*	First Gear on Stud *k*	Second Gear on Stud *j*	Gear on Spindle *h*	Idlers	
								First Hole *k*	Second Hole *l*
192	20	$\frac{4}{20}$	38	40			64	44	
193	20	$\frac{4}{20}$	38	40			56	44	
194	20	$\frac{4}{20}$	38	40			48	44	
195	39	$\frac{8}{39}$	39						
196	49	$\frac{10}{49}$	38						
197	20	$\frac{4}{20}$	38	40			24	56	
198	20	$\frac{4}{20}$	38	56	28	40	32		
199	20	$\frac{4}{20}$	38	100	40	64	32		
200	20	$\frac{4}{20}$	38						
201	20	$\frac{4}{20}$	38	72	24	40	24		24
202	20	$\frac{4}{20}$	38	72	24	40	48		24
203	20	$\frac{4}{20}$	38	40			24	24	44
204	20	$\frac{4}{20}$	38	40			32	24	44
205	41	$\frac{8}{41}$	37						
206	20	$\frac{4}{20}$	38	40			48	24	44
207	20	$\frac{4}{20}$	38	40			56	24	44
208	20	$\frac{4}{20}$	38	40			64	24	44
209	20	$\frac{4}{20}$	38	40			72	24	44
210	21	$\frac{4}{21}$	37						
211	16	$\frac{3}{16}$	36	64			28	44	
212	43	$\frac{8}{43}$	35	86	24	24	48		
213	27	$\frac{5}{27}$	36	72			40	44	
214	20	$\frac{4}{20}$	38	40	56	32	64		24
215	43	$\frac{8}{43}$	35						
216	27	$\frac{5}{27}$	36						
217	21	$\frac{4}{21}$	37	48			64	24	44
218	16	$\frac{3}{16}$	36	64			56	24	44
219	21	$\frac{4}{21}$	37	28			48	24	44
220	33	$\frac{6}{33}$	35						
221	17	$\frac{3}{17}$	33	24			24	56	
222	18	$\frac{3}{18}$	32	24			72	44	
223	43	$\frac{8}{43}$	35	86	48	24	64		24
224	18	$\frac{3}{18}$	32	24			64	44	
225	27	$\frac{5}{27}$	36	24			40	24	44
226	18	$\frac{3}{18}$	32	24			56	44	
227	49	$\frac{8}{49}$	30	56	64	28	72		
228	18	$\frac{3}{18}$	32	24			48	44	
229	18	$\frac{3}{18}$	32	24			44	48	
230	23	$\frac{4}{23}$	34						
231	18	$\frac{3}{18}$	32	32			48	44	
232	29	$\frac{5}{29}$	33						
233	18	$\frac{3}{18}$	32	48			56	44	
234	18	$\frac{3}{18}$	32	24			24	56	
235	47	$\frac{8}{47}$	32						
236	18	$\frac{3}{18}$	32	48			32	44	
237	18	$\frac{2}{18}$	32	48			24	44	
238	18	$\frac{3}{18}$	32	72			24	44	
239	18	$\frac{3}{18}$	32	72	24	64	32		

TABLE I—(*Continued*)

Number of Divisions	Index Circle	Number of Turns of Crank	Graduated Sector Divisions	Gear on Worm *m*	First Gear on Stud *k*	Second Gear on Stud *j*	Gear on Spindle *h*	Idlers	
								First Hole *k*	Second Hole *l*
240	18	$\frac{3}{18}$	32						
241	18	$\frac{3}{18}$	32	72	24	64	32		24
242	18	$\frac{3}{18}$	32	72			24	24	44
243	18	$\frac{3}{18}$	32	64			32	24	44
244	18	$\frac{2}{18}$	32	48			32	24	44
245	49	$\frac{3}{49}$	30						
246	18	$\frac{2}{18}$	32	24			24	24	44
247	18	$\frac{3}{18}$	32	48			56	24	44
248	31	$\frac{2}{31}$	31						
249	18	$\frac{3}{18}$	32	32			48	24	44
250	18	$\frac{2}{18}$	32	24			40	24	44
251	18	$\frac{3}{18}$	32	48	44	32	64		24
252	18	$\frac{2}{18}$	32	24			48	24	44
253	33	$\frac{5}{33}$	29	24			40	56	
254	18	$\frac{3}{18}$	32	24			56	24	44
255	18	$\frac{3}{18}$	32	48	40	24	72		24
256	18	$\frac{3}{18}$	32	24			64	24	44
257	49	$\frac{8}{49}$	30	56	48	28	64		24
258	43	$\frac{7}{43}$	31	32			64	24	44
259	21	$\frac{2}{21}$	28	24			72	44	
260	39	$\frac{6}{39}$	29						
261	29	$\frac{4}{29}$	26	48	64	24	72		
262	20	$\frac{3}{20}$	28	40			28	44	
263	49	$\frac{8}{49}$	30	56	64	28	72		24
264	33	$\frac{5}{33}$	29						
265	21	$\frac{2}{21}$	28	56	40	24	72		
266	21	$\frac{3}{21}$	28	32			64	44	
267	27	$\frac{4}{27}$	28	72			32	44	
268	21	$\frac{3}{21}$	28	28			48	44	
269	20	$\frac{3}{20}$	28	64	32	40	28		24
270	27	$\frac{4}{27}$	28						
271	21	$\frac{3}{21}$	28	56			72	24	
272	21	$\frac{2}{21}$	28	56			64	24	
273	21	$\frac{3}{21}$	28	24			24	56	
274	21	$\frac{3}{21}$	28	56			48	44	
275	21	$\frac{3}{21}$	28	56			40	44	
276	21	$\frac{3}{21}$	28	56			32	44	
277	21	$\frac{3}{21}$	28	56			24	44	
278	21	$\frac{2}{21}$	28	56	32	48	24		
279	27	$\frac{4}{27}$	28	24			32	24	44
280	49	$\frac{7}{49}$	26						
281	21	$\frac{3}{21}$	28	72	24	56	24		24
282	43	$\frac{6}{43}$	26	86	24	24	56		
283	21	$\frac{3}{21}$	28	56			24	24	44
284	21	$\frac{3}{21}$	28	56			32	24	44
285	21	$\frac{3}{21}$	28	56			40	24	44
286	21	$\frac{2}{21}$	28	56			48	24	44
287	21	$\frac{3}{21}$	28	24			24	24	44

TABLE I—(*Continued*)

Number of Divisions	Index Circle	Number of Turns of Crank	Graduated Sector Divisions	Gear on Worm *m*	First Gear on Stud *k*	Second Gear on Stud *j*	Gear on Spindle *h*	Idlers	
								First Hole *k*	Second Hole *l*
288	21	$\frac{3}{21}$	28	28			32	24	44
289	21	$\frac{3}{21}$	28	56			72	24	44
290	29	$\frac{4}{29}$	26						
291	15	$\frac{2}{15}$	25	40			48	44	
292	21	$\frac{3}{21}$	28	28			48	24	44
293	15	$\frac{2}{15}$	25	48	32	40	56		
294	21	$\frac{3}{21}$	28	24			48	24	44
295	15	$\frac{2}{15}$	25	48			32	44	
296	37	$\frac{5}{37}$	26						
297	33	$\frac{4}{33}$	23	28	48	24	56		
298	21	$\frac{3}{21}$	28	28			72	24	44
299	23	$\frac{3}{23}$	25	24			24	56	
300	15	$\frac{2}{15}$	25						
301	43	$\frac{6}{43}$	26	24			48	24	44
302	16	$\frac{2}{16}$	24	32			72	24	
303	15	$\frac{2}{15}$	25	72	24	40	48		24
304	16	$\frac{2}{16}$	24	24			48	44	
305	15	$\frac{2}{15}$	25	48			32	24	44
306	15	$\frac{2}{15}$	25	40			32	24	44
307	15	$\frac{2}{15}$	25	72	48	40	56		24
308	16	$\frac{2}{16}$	24	32			48	44	
309	15	$\frac{2}{15}$	25	40			48	24	44
310	31	$\frac{4}{31}$	24						
311	16	$\frac{2}{16}$	24	64	24	24	72		
312	39	$\frac{5}{39}$	24						
313	16	$\frac{2}{16}$	24	32			28	56	
314	16	$\frac{2}{16}$	24	32			24	56	
315	16	$\frac{2}{16}$	24	64			40	24	
316	16	$\frac{2}{16}$	24	64			32	44	
317	16	$\frac{2}{16}$	24	64			24	44	
318	16	$\frac{2}{16}$	24	56	28	48	24		
319	29	$\frac{4}{29}$	26	48	64	24	72		24
320	16	$\frac{2}{16}$	24						
321	16	$\frac{2}{16}$	24	72	24	64	24		24
322	23	$\frac{3}{23}$	25	32			64	24	44
323	16	$\frac{2}{16}$	24	64			24	24	44
324	16	$\frac{2}{16}$	24	64			32	24	44
325	16	$\frac{2}{16}$	24	64			40	24	44
326	16	$\frac{2}{16}$	24	32			24	24	44
327	16	$\frac{2}{16}$	24	32			28	24	44
328	41	$\frac{5}{41}$	23						
329	16	$\frac{2}{16}$	24	64	24	24	72		24
330	33	$\frac{4}{33}$	23						
331	16	$\frac{2}{16}$	24	64	44	24	48		24
332	16	$\frac{2}{16}$	24	32			48	24	44
333	18	$\frac{2}{18}$	21	24			72	44	
334	16	$\frac{2}{16}$	24	32			56	24	44
335	33	$\frac{4}{33}$	23	72	48	44	40		24

TABLE I—(*Continued*)

Number of Divisions	Index Circle	Number of Turns of Crank	Graduated Sector Divisions	Gear on Worm *m*	First Gear on Stud *k*	Second Gear on Stud *j*	Gear on Spindle *h*	Idlers	
								First Hole *k*	Second Hole *l*
336	16	$\frac{2}{16}$	24	32			64	24	44
337	43	$\frac{5}{43}$	21	86	40	32	56		
338	16	$\frac{2}{16}$	24	32			72	24	44
339	18	$\frac{2}{18}$	21	24			56	44	
340	17	$\frac{2}{17}$	22						
341	43	$\frac{5}{43}$	21	86	24	32	40		
342	18	$\frac{2}{18}$	21	32			64	44	
343	15	$\frac{2}{15}$	25	40	64	24	86		24
344	43	$\frac{5}{43}$	21						
345	18	$\frac{2}{18}$	21	24			40	56	
346	18	$\frac{2}{18}$	21	72	56	32	64		
347	43	$\frac{5}{43}$	21	86	24	32	40		24
348	18	$\frac{2}{18}$	21	24			32	56	
349	18	$\frac{2}{18}$	21	72	44	24	48		
350	18	$\frac{2}{18}$	21	72	40	32	64		
351	18	$\frac{2}{18}$	21	24			24	56	
352	18	$\frac{2}{18}$	21	72	24	24	64		
353	18	$\frac{2}{18}$	21	72			56	24	
354	18	$\frac{2}{18}$	21	72			48	24	
355	18	$\frac{2}{18}$	21	72			40	24	
356	18	$\frac{2}{18}$	21	72			32	24	
357	18	$\frac{2}{18}$	21	72			24	44	
358	18	$\frac{2}{18}$	21	72	32	48	24		
359	43	$\frac{5}{43}$	21	86	48	32	100		24
360	18	$\frac{2}{18}$	21						
361	19	$\frac{2}{19}$	19	32			64	44	
362	18	$\frac{2}{18}$	21	72	28	56	32		24
363	18	$\frac{2}{18}$	21	72			24	24	44
364	18	$\frac{2}{18}$	21	72			32	24	44
365	20	$\frac{2}{20}$	18	32	48	24	56		
366	18	$\frac{2}{18}$	21	48			32	24	44
367	18	$\frac{2}{18}$	21	72			56	24	24
368	18	$\frac{2}{18}$	21	72	24	24	64		24
369	41	$\frac{4}{41}$	18	32	56	28	64		
370	37	$\frac{4}{37}$	20						
371	21	$\frac{2}{21}$	18	32	56	24	64		
372	18	$\frac{2}{18}$	21	48			64	24	44
373	20	$\frac{2}{20}$	18	40	48	32	72		
374	18	$\frac{2}{18}$	21	72	64	32	56		24
375	18	$\frac{2}{18}$	21	24			40	24	44
376	47	$\frac{5}{47}$	19						
377	29	$\frac{3}{29}$	19	24			24	56	
378	18	$\frac{2}{18}$	21	32			64	24	44
379	20	$\frac{2}{20}$	18	48	56	40	72		
380	19	$\frac{2}{19}$	19						
381	18	$\frac{2}{18}$	21	24			56	24	44
382	20	$\frac{2}{20}$	18	40			72	24	

TABLE II
COMPOUND INDEXING

Number of Divisions	Moves of Crank	Total Turns of Work	Number of Divisions	Moves of Crank	Total Turns of Work
51	$8\frac{41}{47}-\frac{12}{49}$	11	118	$1\frac{8}{39}+\frac{24}{49}$	5
53	$6\frac{43}{47}-\frac{6}{49}$	9	119	$3\frac{4}{23}-\frac{16}{33}$	8
57	$4\frac{40}{47}+\frac{3}{49}$	7	121	$1\frac{14}{47}-\frac{15}{49}$	3
59	$7\frac{10}{47}+\frac{12}{49}$	11	122	$3\frac{41}{43}-\frac{17}{49}$	11
61	$3\frac{42}{47}+\frac{2}{49}$	6	123	$1\frac{12}{43}+\frac{17}{49}$	5
63	$4\frac{19}{29}+\frac{14}{33}$	8	125	$2\frac{33}{41}-\frac{12}{49}$	8
67	$2\frac{27}{41}+\frac{16}{49}$	5	126	$3\frac{16}{19}-\frac{7}{20}$	11
69	$\frac{21}{23}-\frac{11}{33}$	1	127	$2\frac{23}{39}+\frac{12}{49}$	9
71	$3\frac{34}{41}-\frac{22}{49}$	6	129	$5\frac{24}{41}+\frac{15}{49}$	19
73	$6\frac{28}{47}-\frac{1}{49}$	12	131	$2\frac{40}{43}+\frac{21}{49}$	11
77	$\frac{9}{21}+\frac{3}{33}$	1	133	$3\frac{23}{29}-\frac{16}{33}$	11
79	$2\frac{42}{43}+\frac{3}{49}$	6	134	$3\frac{27}{47}+\frac{15}{49}$	13
81	$5\frac{5}{41}-\frac{9}{49}$	10	137	$3\frac{17}{43}-\frac{9}{49}$	11
83	$3\frac{45}{47}-\frac{5}{49}$	8	138	$\frac{11}{33}-\frac{1}{23}$	1
87	$\frac{23}{29}-\frac{11}{33}$	1	139	$2\frac{25}{37}+\frac{24}{49}$	11
89	$3\frac{28}{39}-\frac{6}{49}$	8	141	$1\frac{32}{39}+\frac{22}{49}$	8
91	$\frac{6}{39}+\frac{14}{49}$	1	142	$4\frac{1}{47}+\frac{10}{49}$	15
93	$\frac{3}{31}+\frac{11}{33}$	1	143	$1\frac{36}{47}-\frac{18}{49}$	5
96	$\frac{3}{18}+\frac{5}{20}$	1	146	$2\frac{3}{37}-\frac{8}{49}$	7
97	$4\frac{27}{41}-\frac{6}{49}$	11	147	$\frac{13}{39}-\frac{3}{49}$	1
99	$\frac{15}{27}-\frac{5}{33}$	1	149	$3\frac{5}{43}-\frac{8}{49}$	11
101	$4\frac{32}{43}-\frac{19}{49}$	11	151	$1\frac{42}{43}-\frac{6}{49}$	7
102	$4\frac{17}{43}-\frac{4}{49}$	11	153	$2\frac{45}{47}-\frac{4}{49}$	11
103	$1\frac{8}{43}+\frac{18}{49}$	4	154	$\frac{8}{21}-\frac{4}{33}$	1
106	$2\frac{38}{41}+\frac{23}{49}$	9	157	$2\frac{23}{31}+\frac{2}{33}$	11
107	$2\frac{21}{31}-\frac{2}{23}$	7	158	$5\frac{5}{43}-\frac{15}{49}$	19
109	$2\frac{19}{39}+\frac{4}{49}$	7	159	$2\frac{7}{37}+\frac{16}{49}$	10
111	$3\frac{29}{47}+\frac{17}{49}$	11	161	$2\frac{10}{39}-\frac{1}{49}$	9
112	$4\frac{10}{31}-\frac{13}{33}$	11	162	$1\frac{30}{39}-\frac{2}{49}$	7
113	$3\frac{26}{47}-\frac{18}{49}$	9	163	$3\frac{7}{37}-\frac{24}{49}$	11
114	$1\frac{35}{37}+\frac{25}{49}$	7	166	$1\frac{19}{43}+\frac{12}{49}$	7
117	$7\frac{1}{47}-\frac{9}{49}$	20	167	$2\frac{1}{29}+\frac{4}{33}$	9

TABLE II—(*Continued*)

Number of Divisions	Moves of Crank	Total Turns of Work	Number of Divisions	Moves of Crank	Total Turns of Work
169	$1\frac{32}{37}+\frac{13}{49}$	9	212	$3\frac{4}{47}+\frac{6}{49}$	17
171	$1\frac{29}{47}+\frac{1}{49}$	7	213	$1\frac{18}{39}+\frac{2}{49}$	8
173	$1\frac{7}{43}+\frac{11}{49}$	6	214	$3\frac{9}{47}-\frac{19}{49}$	15
174	$\frac{11}{33}-\frac{3}{29}$	1	217	$2\frac{3}{43}+\frac{16}{49}$	13
175	$1\frac{4}{31}+\frac{8}{33}$	6	218	$1\frac{22}{47}-\frac{9}{49}$	7
176	$1\frac{14}{43}+\frac{13}{49}$	7	219	$3\frac{29}{43}-\frac{10}{49}$	19
177	$2\frac{19}{47}+\frac{4}{29}$	11	221	$1\frac{5}{47}-\frac{1}{49}$	6
178	$3\frac{28}{47}+\frac{11}{49}$	17	222	$2\frac{8}{43}-\frac{10}{49}$	11
179	$2\frac{34}{47}-\frac{13}{49}$	11	223	$2\frac{26}{43}+\frac{13}{49}$	16
181	$2\frac{8}{43}+\frac{12}{49}$	11	224	$2\frac{6}{23}+\frac{2}{33}$	13
182	$\frac{3}{39}+\frac{7}{49}$	1	225	$\frac{5}{18}-\frac{2}{20}$	1
183	$1\frac{24}{41}+\frac{8}{49}$	8	226	$1\frac{38}{39}+\frac{16}{49}$	13
186	$\frac{17}{31}-\frac{11}{33}$	1	227	$3\frac{3}{43}+\frac{5}{49}$	18
187	$1\frac{20}{47}+\frac{14}{49}$	8	228	$2\frac{8}{41}-\frac{13}{49}$	11
189	$2\frac{26}{41}-\frac{15}{49}$	11	229	$2\frac{19}{41}-\frac{18}{49}$	12
191	$1\frac{38}{47}+\frac{14}{49}$	10	231	$\frac{3}{21}+\frac{1}{33}$	1
192	$2\frac{22}{41}-\frac{12}{49}$	11	233	$1\frac{36}{47}+\frac{6}{49}$	11
193	$1\frac{5}{37}-\frac{15}{49}$	4	234	$2\frac{21}{29}+\frac{6}{33}$	17
194	$2\frac{22}{37}-\frac{16}{49}$	11	236	$2\frac{30}{43}+\frac{9}{49}$	17
197	$1\frac{39}{43}+\frac{16}{49}$	11	237	$2\frac{12}{47}-\frac{3}{49}$	13
198	$\frac{3}{27}+\frac{3}{33}$	1	238	$2\frac{3}{31}+\frac{14}{33}$	15
199	$2\frac{12}{41}-\frac{4}{49}$	11	239	$1\frac{23}{43}+\frac{15}{49}$	11
201	$2\frac{18}{47}+\frac{10}{49}$	13	241	$1\frac{1}{41}+\frac{23}{49}$	9
202	$3\frac{10}{41}+\frac{6}{49}$	17	242	$2\frac{23}{41}-\frac{4}{49}$	15
203	$1\frac{23}{39}+\frac{9}{49}$	9	243	$1\frac{29}{41}-\frac{3}{49}$	10
204	$2\frac{20}{41}+\frac{3}{49}$	13	244	$2\frac{15}{31}+\frac{10}{33}$	17
206	$2\frac{34}{39}+\frac{2}{49}$	15	246	$1\frac{6}{43}-\frac{16}{49}$	5
207	$3\frac{8}{41}-\frac{24}{49}$	14	247	$2\frac{15}{43}-\frac{4}{49}$	14
208	$1\frac{19}{47}+\frac{16}{49}$	9	249	$3\frac{4}{43}-\frac{2}{49}$	19
209	$\frac{8}{49}+\frac{9}{41}$	2	250	$2\frac{9}{37}-\frac{8}{49}$	13
211	$1\frac{28}{39}+\frac{18}{49}$	11			

MILLING-MACHINE WORK

(PART 5)

OPERATION OF MILLING MACHINE

SPIRAL WORK

GENERATION OF HELIX

1. Combined Endwise and Rotary Movements. Much milling is done on work held between the index-head centers or in the chuck of a universal index head, the work being given a rotary motion and an endwise motion at the same time. If the index-head spindle and the feed-screw are geared together, a cutting tool in contact with the work will trace a spiral curve on its surface. If the work is cylindrical, the spiral will be of the form known as a *helix*, and if the work is conical, a *conical spiral* will be formed. The endwise motion of the milling-machine table is obtained by turning the feed-screw either by hand or automatically, and the index-head spindle receives its motion from the feed-screw through a train of gears.

2. Lead of Helix.—A helix is a form of spiral curve formed on the surface of a cylindrical piece, as, for example, a thread on a screw. In a helix, the distance advanced by the curve in 1 complete turn around the work is called the **lead**; that is, it is the distance from a point on one turn to a similar point on the next turn, measured in a direction parallel to the axis of

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the work. In milling-machine work, the lead is generally expressed in inches and fractional parts of an inch.

3. Angle of Helix.—The length of a helix is represented by the hypotenuse of a right-angled triangle having one side equal to the lead of the helix and the other side equal to the circumference of the cylinder on which the helix is formed. Thus, let Fig. 1 (*a*) represent a right-angled triangle cut out of paper, where the side *a*, adjacent to the right angle, is equal to the circumference of the cylinder *d* shown in (*b*), and the side *b* is the lead. Then, when this triangle is wound around *d*, as shown in (*b*), the side *c* will form a helix having a diameter equal

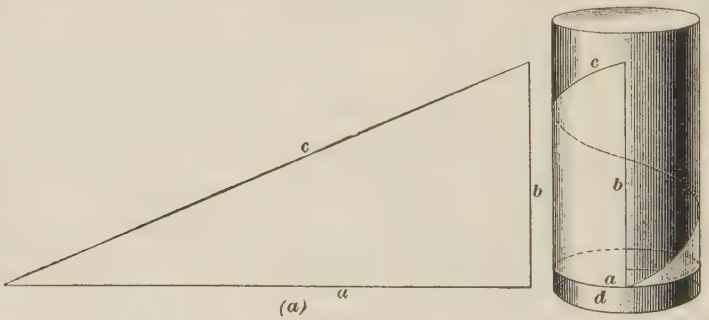


FIG. 1

to *d*, and a lead *b*. The angle included between the lead *b* and the helix length *c* is the angle of the helix.

4. Finding Angle of Helix.—The tangent of an angle of a right-angled triangle is equal to the side opposite divided by the side adjacent. In Fig. 1 the tangent of the angle of the helix is equal to the length of the side *a* divided by the length of the side *b*; that is, it is equal to the circumference of the cylinder divided by the lead of the helix. To find the angle of a helix, the following rule may be used:

Rule.—*To find the angle of a helix, multiply the diameter of the helix by 3.1416 and divide the product by the lead. The quotient is the tangent of the angle of the helix, and the corresponding angle may be found from a table of natural tangents.*

EXAMPLE.—A helix $4\frac{1}{2}$ inches in diameter has a lead of 16 inches. What is the angle of the helix?

SOLUTION.—Applying the rule,

$$\frac{4\frac{1}{2}\times 3.1416}{16} = .8836$$

From a table of natural tangents, the angle whose tangent is .8836 is found to be 41° 28′, nearly. Ans.

5. Finding Lead for Given Angle of Helix.—It often is necessary to find what lead of helix will give a certain angle of helix, the diameter of the helix being known. This may be calculated by the following rule:

Rule.—*To find the lead required to give a desired angle of helix, multiply the diameter of the helix by 3.1416 and divide the product by the tangent of the angle of the helix.*

EXAMPLE.—A helix is to have an angle of helix of 30° 45′ and a diameter of $3\frac{1}{4}$ inches. What must be the lead of the helix?

SOLUTION.—From a table of natural tangents, the tangent corresponding to 30° 45′ is .5950. Applying the rule, the lead is

$$\frac{3\frac{1}{4}\times 3.1416}{.5950} = 17.16 \text{ in.} \quad \text{Ans.}$$

6. Connecting Index-Head Spindle and Feed-Screw. The feed-screw and index-head spindle may be connected by gearing in many ways; as, in nearly all designs of universal index head, the worm-shaft and the feed-screw are at right angles to each other, it is necessary in these designs to introduce a pair of miter gears, or spiral gears, into the gear-train to allow the worm-shaft and the feed-screw to be connected by spur gearing.

7. One of the simplest designs for connecting the feed-screw and the index-head spindle is shown in Fig. 2. The worm-shaft *a* carries a miter gear *b*, which, normally, is free on the worm-shaft. The index plate *c* is fastened to the hub of the miter gear *b*, and is ordinarily prevented from rotating by a stop-pin in the frame of the index head. The index crank *d* is attached to the worm-shaft. Now, if the stop-pin is withdrawn, and the latch pin is dropped into a hole of the index plate, the worm-

shaft and the miter gear b are locked together, so that any motion transmitted to the miter gear will also be transmitted to the worm-shaft and then, through the intervention of the worm-wheel e, to the index-head spindle f. The miter wheel b meshes with a miter gear g, which is keyed to the shaft h; the first change gear k of the train of spur gearing connecting the

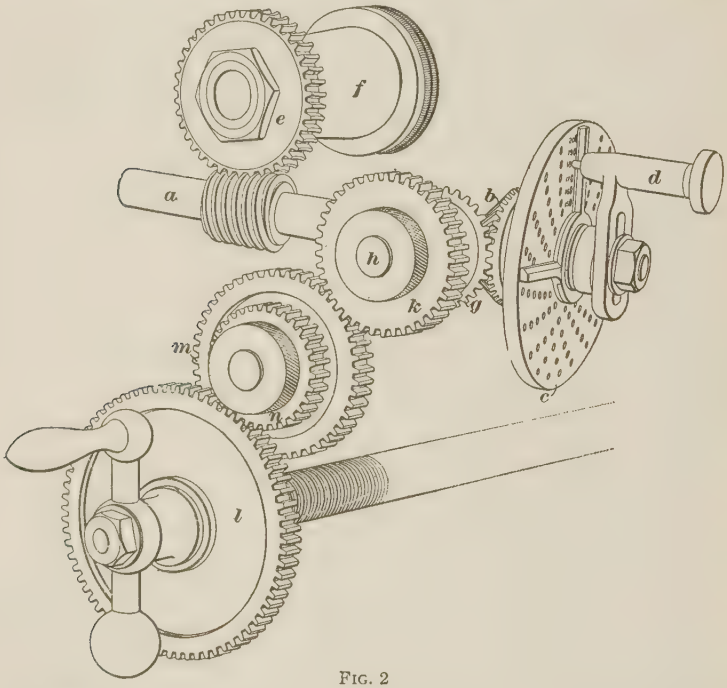


FIG. 2

spindle and feed-screw is attached to the other end of the shaft h. The first gear k is called the **worm-gear,** from the fact that it operates the worm.

8. A spur gear l, Fig. 2, known as the **feed-screw gear,** is placed on the feed-screw; the gears k and l are then connected by the two gears m and n placed on the same sleeve, which is mounted on an adjustable stud fastened in any suitable manner to the frame of the index head or the table of the machine. As a general rule, another stud is provided on which an idler can be

placed. This idler may be placed either between *k* and *m* or between *l* and *n*; it will not change the speed of the gear-train, but only the direction of rotation of the index-head spindle, and the direction of advance of the helix. In most milling machines, the use of the idler will make a left-hand helix; owing to the difference in construction of the various machines, it is better, however, to determine this separately for each machine than to rely on the presence of an idler as a guarantee of a left-hand helix.

9. As the index-head spindle and the feed-screw are positively connected, the relation between the rotation of the spindle and the advance of the table remains constant, and the resulting helix will have a uniform lead. The lead can be changed only by changing the relative speeds of the gears connecting the feed-screw and the spindle. Index heads have the gearing that connects the worm-shaft to the worm-gear *k* so arranged that it cannot be changed, and these gears are called the *fixed gears*. Different helixes can be obtained only by changing the gears *k*, *l*, *m*, and *n*, Fig. 2, known as the *change gears*. It is customary to call the first gear slipped on the stud, or the gear *m*, the **first gear on stud,** and the gear *n* the **second gear on stud.**

10. It will be noticed that the change gears in Fig. 2 form a train of compound gearing. The reason for the almost universal adoption of compound gearing is that, with a given number of change gears, a much larger range of combinations is possible than can be obtained with a simple gear-train. As previously stated, the index plate is locked to the worm-shaft and rotates with it during the cutting operation. Indexing is done after the completion of the cut and while the machine is standing still, first locking the index plate by inserting the stop-pin, and then giving the index crank the required number of turns. The index plate is now unlocked by pulling out the stop-pin, and the machine is ready for the next turn.

11. A stiffer and more compact design of gear-train for connecting the index-head spindle and feed-screw is shown

in Fig. 3. The worm-shaft *a* carries a spur gear *b* that can be locked to the worm-shaft by dropping the latch pin into one of the holes of the index plate *c*. The spur gear *b* meshes with an idler *d* carried on a stud; this idler in turn drives a spur gear *e* that is keyed to one end of the shaft *f*. A spiral gear *g* is keyed to the other end of the shaft *f*, and meshes with a similar spiral gear *h* keyed to a shaft *i*, which is at right angles to the

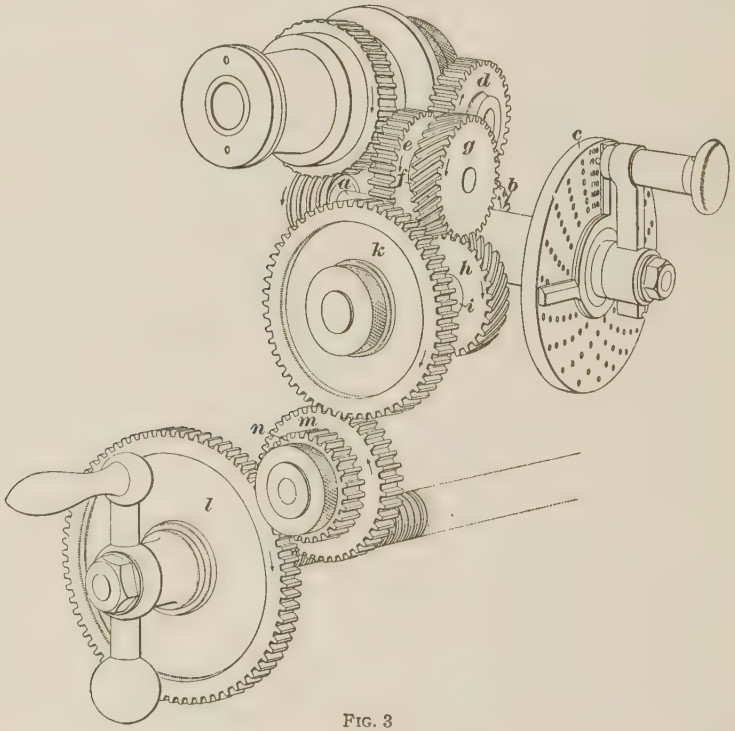


FIG. 3

worm-shaft, and hence, parallel to the feed-screw. The shaft *i* carries the gear on the worm-stud *k*, which meshes with the first gear *m* on the stud. The second gear *n* on the stud rotates with *m* and meshes with the feed-screw gear *l*. In this gear-train, the gears *b*, *d*, *e*, *g*, and *h* cannot be changed; different helixes are produced by changing the change gears *k*, *l*, *m*, and *n*, as in the previous case.

CALCULATION OF CHANGE GEARS

12. Lead of Machine.—The lead of the milling machine is the distance that the table will travel during one turn of the index spindle, when change gears of equal sizes are used. The change gears furnished with the Brown & Sharpe milling machine have the following numbers of teeth: 24, 28, 32, 40, 44, 48, 56, 64, 72, 76, 80, 86, and 100. If only one universal milling machine were available, it is evident that it would be impossible to select four change gears of equal sizes to find the lead practically. If, however, a number of machines were available, a set of four 64-tooth gears, for example, could be selected and placed on one machine. All four gears need not be necessarily of the same size; for example, two 72-tooth gears could be used, one on the screw and one on the worm, and any two equal gears, as two 48-tooth gears, on the stud. The relative speeds would remain unchanged, as each pair would form a single idler. The lead of the machine may be found by the following rule:

Rule.—*To find the lead of the machine, multiply the lead of the feed-screw by the number of revolutions of the gear on the worm-stud required to produce 1 revolution of the index-head spindle.*

EXAMPLE.—It is found by actual count that 56 revolutions of the gear on the worm-stud are required to produce 1 revolution of the index-head spindle. If the feed-screw has a lead of $\frac{1}{4}$ inch, what is the lead of the machine?

SOLUTION.—Applying the rule, the lead is

$$\tfrac{1}{4} \times 56 = 14 \text{ in.} \quad \text{Ans.}$$

13. Simple Gearing.—The lead of the helix having been given, the ratio between the revolutions of the gear on the worm-stud and the revolutions of the feed-screw is equal to the ratio of the lead of the helix to the lead of the machine; that is, it is equal to $\frac{\text{lead of the helix}}{\text{lead of the machine}}$. Then, for simple gearing it only remains to choose gears that have this ratio. This is most conveniently done by raising both terms of the ratio to higher terms that correspond with the teeth of the gears

available. When the lead of the helix is less than the lead of the machine, the gear on the worm-stud will be the smaller gear of the two; when the lead of the helix is greater than the lead of the machine, the gear on the worm-stud will be the larger of the two.

EXAMPLE.—If the lead of the required helix is 14 inches and the lead of the machine is 10 inches, what gears may be used, for simple gearing?

SOLUTION.—The ratio of the gears, according to the foregoing statement, is $\frac{14}{10}$. As there are no gears having 14 and 10 teeth, multiply both numerator and denominator by the same number, as 4, for example. Then, $\frac{14}{10}\times\frac{4}{4}=\frac{56}{40}$. As the set of gears contains 56- and 40-tooth gears, these two sizes may be used. Ans.

The gear represented by the numerator 56 should be placed on the worm-stud, as at *k*, Fig. 3; and the gear represented by the denominator 40 should be placed on the feed-screw, as at *l*. The gears *m* and *n* should then be of the same size, to serve as an idler.

14. When the two change gears of the train of simple gearing are given, the lead of the helix that will be cut may be found by the following rule:

Rule.—*To find the lead of the helix that will be cut with simple gearing, multiply the number of teeth of the gear on the worm-stud by the lead of the machine, and divide the product by the number of teeth of the feed-screw gear.*

EXAMPLE.—The gear on the worm-stud has 48 teeth and the feed-screw gear 100 teeth. What is the lead of the helix that will be cut if the lead of the machine is 12 inches?

SOLUTION.—Applying the rule, the lead is

$$\frac{48\times12}{100}=5.76 \text{ in.} \quad \text{Ans.}$$

15. Compound Gearing.—The ratio of the gears for compound gearing is the same as for simple gearing, or $\frac{\text{lead of the helix}}{\text{lead of the machine}}$. This ratio must be resolved into two fractional factors and a pair of gears selected for each, as in simple gearing. It is not necessary to multiply the terms of

both factors by the same number; all that is required is that the two terms of each factor be multiplied by the same number. After factoring the ratio, which is done by inspection, the numerators of the factors will represent the driven gears of the gear-train, and the denominators will represent the drivers.

EXAMPLE.—What change gears may be used to cut a helix with a lead of 24 inches, if the lead of the machine is 10 inches?

SOLUTION.—The ratio is $\frac{24}{10}$, which, when factored, becomes $\frac{24}{10}=\frac{3\times 8}{2\times 5}$ $=\frac{3}{2}\times\frac{8}{5}$. This means that one pair of gears that mesh must have the ratio of $\frac{3}{2}$ and the other pair the ratio of $\frac{8}{5}$. Now, $\frac{3}{2}\times\frac{16}{16}=\frac{48}{32}$, and $\frac{8}{5}\times\frac{8}{8}=\frac{64}{40}$. As there are gears having 48, 32, 64, and 40 teeth, these sizes of change gears may be used. Ans.

The question of where each pair of meshing gears must be placed can easily be answered when it is considered that if the lead of the helix to be cut is smaller than the lead of the machine, the gear on the worm-stud must run faster than the feed-screw gear. When the lead of the helix is greater than the lead of the machine, the gear on the worm-stud must run slower than the feed-screw gear.

16. When the lead of the helix is a whole number of inches, it is usually quite easy to factor the ratio. This factoring can sometimes be made easier by raising the ratio to higher terms by multiplying the numerator and denominator by some number. For instance, the ratio $\frac{17}{10}$ is rather difficult to factor as it stands, but by raising it to higher terms, as by multiplying by 4, the fraction $\frac{68}{40}$ is obtained, which readily resolves into the factors $\frac{17}{20}\times\frac{4}{2}$, or $\frac{17}{2}\times\frac{4}{20}$, or $\frac{34}{8}\times\frac{2}{5}$, or $\frac{34}{5}\times\frac{2}{8}$.

Take, now, the case of a helix having a lead expressed in whole inches and part of an inch, as, for instance, $14\frac{1}{4}$ inches. Let the lead of the machine be 12 inches. Then, the ratio is $\frac{14\frac{1}{4}}{12}$, which in this form is rather difficult to factor. Now, suppose that it is raised to higher terms by multiplying it by a number

that will make the numerator $14\frac{1}{4}$ a whole number. In this case 4, or a multiple of 4, will be the number to use. Then, $\frac{14\frac{1}{4}}{12}\times\frac{4}{4}=\frac{57}{48}$ is the ratio. This readily resolves into a number of factors, as $\frac{3}{4}\times\frac{19}{12}$, or $\frac{3}{12}\times\frac{19}{4}$, or $\frac{19}{6}\times\frac{3}{8}$, or $\frac{19}{8}\times\frac{3}{6}$, or $\frac{3}{16}\times\frac{19}{3}$, or $\frac{19}{16}\times\frac{3}{3}$, etc.

17. When it is not feasible to factor the ratio, or to get gear combinations that include available gears, the proper gear combination can often be discovered only by a cut-and-try method; that is, by repeated trials. In many cases it is not possible to cut the required helix at all, but the machine may often be geared to cut a spiral that approaches the desired helix somewhat closely. Here the cut-and-try method must also be followed. Two methods of procedure may be adopted: three gears of the set may be assumed and the fourth calculated, or a combination of four gears may be selected and the resulting helix found by calculation. When three gears of the set are assumed, the fourth may be calculated as follows:

Rule.—*Multiply the lead of the helix in inches by the number of teeth of the feed-screw gear and the first gear on stud. Divide the product by the product of the number of teeth of the second gear on stud and the lead of the machine in inches. The quotient will be the number of teeth of the worm-gear.*

Example 1.—If the feed-screw gear has 40 teeth, the first gear on stud 32 teeth, the second gear on stud 56 teeth, the lead of the machine being 10 inches, and the lead of the helix to be cut being 28 inches, what should be the number of teeth of the worm-gear?

Solution.—Applying the rule,

$$\frac{28\times40\times32}{56\times10}=64 \text{ teeth.} \quad \text{Ans.}$$

Example 2.—A helix having a lead of 39 inches is to be cut. The feed-screw gear has 40 teeth, the first gear on stud 32 teeth, the second gear on stud 56 teeth, and the lead of the machine is 10 inches. What number of teeth should the gear on worm-stud have?

Solution.—Applying the rule,

$$\frac{39\times40\times32}{56\times10}=89\tfrac{1}{7} \text{ teeth}$$

As a gear with this number of teeth is an impossibility, the calculation shows that with the gears selected it is not possible to cut the required spiral. If a gear with 89 teeth is available, a fairly close approach to the required spiral may, however, be cut. Ans.

18. When the four gears and the lead of the machine are known, the lead of the resulting helix may be calculated as follows:

Rule.— *Multiply the lead of the machine by the number of teeth of the gear on the worm-stud and the number of teeth of the second gear on stud. Divide this product by the product of the number of teeth of the feed-screw gear and the number of teeth of the first gear on stud. The quotient is the lead of the resulting helix.*

EXAMPLE.—In example 2, Art. **17**, it was stated that a fair approximation to the required helix might be cut with a gear on the worm-stud having 89 teeth. Calculate the lead of the helix that will actually be cut.

SOLUTION.—Applying the rule, the lead is

$$\frac{10\times89\times56}{40\times32}=38.9375 \text{ in.} \quad \text{Ans.}$$

CUTTING HELIXES

19. Cutters and Profiles.—Familiar examples of the cutting of helical grooves are the fluting of helical-tooth reamers and of twist drills, the cutting of the spaces of helical-tooth milling cutters, the cutting of screw gears, etc. The section of a helical groove is found by cutting across the groove at right angles to the sides of the groove but not at right angles to the axis of the work; whereas, the section of a straight groove that is parallel to the axis of the work is taken at right angles to the groove and the axis, or, practically, it is shown directly on the end of the work. This must be kept in mind when selecting a cutter for a helical groove. When the profile of the groove is symmetrical, it can be cut with either an end mill or a formed cutter of the required shape; but when the groove has an unsymmetrical profile, an end mill cannot be used. When an end mill is employed for cutting the groove, the table, when arranged to swivel, as is the case in horizontal universal milling machines,

must be set to zero, that is, so that its direction of motion is perpendicular to the axis of the cutter.

20. A double-angle milling cutter must be used to cut unsymmetrical grooves, and can also be advantageously used for many symmetrical grooves. It requires the table to be set to the angle of the helix. As a general rule, the graduations of a milling-machine table are so arranged that when the table is set so that the graduations read to the angle of the helix, it will make the required angle to the axis of rotation of the cutter. If the table is not set to the angle of the helix, the resulting groove will not have the same profile as the cutter. This fact can often be utilized when a cutter of the right width is not available and the exact shape of the profile need not be particularly accurate.

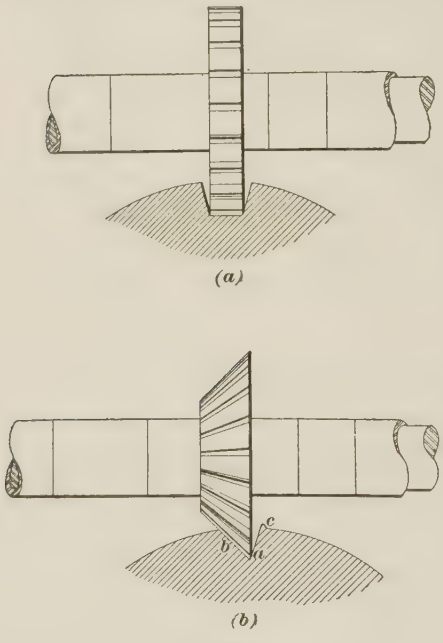


FIG. 4

21. Helical Grooves With Parallel Sides.—In milling a helical groove with the kind of plain cutter that will produce a straight groove with parallel sides, as a slitting saw, for instance, it will be found that the resulting groove will *not* have parallel sides, but will be enlarged at the top, about as shown in Fig. 4 (*a*). Therefore, when a helical groove with parallel sides is to be cut, a plain cutter cannot be employed; but an end mill will be found to answer this purpose.

22. Helical Grooves With Inclined Sides.—When an attempt is made to cut an angular helical groove with a

single-angle cutter, it will be found that the angle between the sides of the groove will not be equal to the angle of the cutter, but will be larger at the top, as shown in Fig. 4 (*b*); also, the side *a* will be very rough as compared with the side *b*, and a burr will be formed at *c*. From these facts it is shown that a single-angle cutter will not cut a groove having its own profile and will neither cut radial faces nor mill a smooth groove. The following general conclusions may also be drawn from the facts stated in this and the preceding article: No plain or single-angle cutter will produce its own profile in a helical groove when it has on one or both sides teeth that are radial or at right angles to the axis of the cutter or arbor by which it is driven. An end mill must be used if a helical groove of rectangular section is to be milled. Any cutter, except an end mill, that is required to produce its own profile in a helical groove must be wider near the arbor, or at the roots of the teeth, than at the points of the teeth; hence, when angular grooves are to be milled, double-angle cutters should always be used. Such a cutter will reproduce its own profile, as shown in Fig. 5, and mill both sides of the groove smooth.

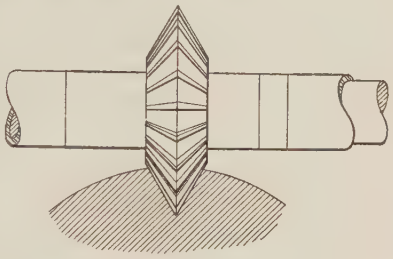
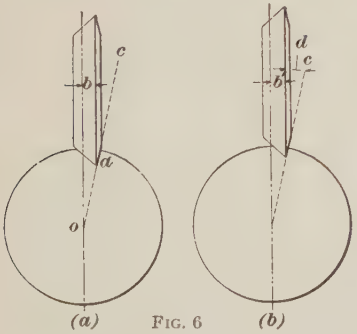


FIG. 5



(*a*) FIG. 6 (*b*)

23. Helical Grooves With One Side Radial.—In much of the helical work done with angular cutters one side of the groove must be radial. For this work, double-angle cutters must be selected, and they must be set sufficiently off center to make the required side of the groove radial when the cutter is sunk into the work to the proper depth. Fig. 6 (*a*) shows a double-angle cutter sunk into the

work until the side *a* of the groove is radial. The amount that the cutter must be set off center is the distance *b*. This distance varies with the depth of the cut; thus, in order that the side *a* may remain radial for a greater or smaller depth of cut, the cutter must be shifted radially, that is, along the line *o c*. Then, for a smaller depth of cut, as shown in (*b*), the distance *b'* that the cutter is off center will be greater than *b*, and for a greater depth of cut, this distance will be smaller. The distance that the cutter is to be set off center is found by the following rule:

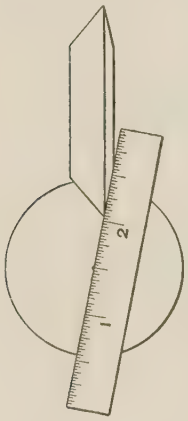


FIG. 7

Rule.—*To find how far the cutter is to be set off center, from the radius of the work subtract the depth of the cut, measured radially, and multiply the remainder by the sine of the angle included between that side of the cutter with which the radial side of the groove is to be cut and a line perpendicular to the axis of the cutter, as the angle* ***d*** *of the cutter cutting the radial side of the groove in Fig. 6 (b).*

EXAMPLE.—The angle *d*, Fig. 6 (*b*), being 12°, how much should the cutter be set off center when the work is 3 inches in diameter and the radial depth of the cut .4 inch?

SOLUTION.—From a table of natural sines, the sine of 12° is .2079. For the class of work usually done, it is near enough to call the sine .2. Applying the rule, the offset is

$$(\tfrac{3}{2}-.4)\times.2=(1.5-.4)\times.2=1.1\times.2=.22 \text{ in.} \quad \text{Ans.}$$

24. If the effect of the depth of the cut is left entirely out of consideration, the amount that the cutter is set off center is found by multiplying the diameter of the work by half the sine of the angle, as the angle *d*, Fig. 6 (*b*). On this basis the approximate values in Table I have been calculated for the angles most commonly used for double-angle cutters. The rules here given for the offset of double-angle cutters apply to straight grooves as well as to helical grooves. In the case of a helical groove, the cutter should be set correctly while the line of motion is at right angles to the axis of rotation of the cutter;

the table is to be swiveled to the angle of the helix after setting the cutter off center. Most helical mills are fluted with a 12°—40° double-angle cutter, which is always set $\frac{1}{10}$ of the diameter of the work off center. If a cutter $3\frac{1}{2}$ inches in diameter is to be fluted with a 12°—40° cutter the points of the cutter would be set $\frac{1}{10} \times 3.5 = .35$ inch off center, or .35 inch from the center line to the point of a cutter tooth. Another way is to set the cutter to about the depth of cut required and then move it sidewise until the edge of a rule applied along the edge of the tooth that cuts the radial face of the groove will pass across the index center, as in Fig. 7.

TABLE I

OFFSET OF DOUBLE-ANGLE CUTTERS

Angle Degrees	Offset
12	Diameter × .1
$27\frac{1}{2}$	Diameter × .23
30	Diameter × .25
40	Diameter × .32
45	Diameter × .35
48	Diameter × .37
53	Diameter × .4

25. Direction of Rotation of Work.—In cutting helical grooves with double-angle cutters having unequal angles, the work should always revolve toward that side of the cutter where the teeth have the greater angle. Fig. 8 shows the four cases that arise in practice; in each case, the side *a*

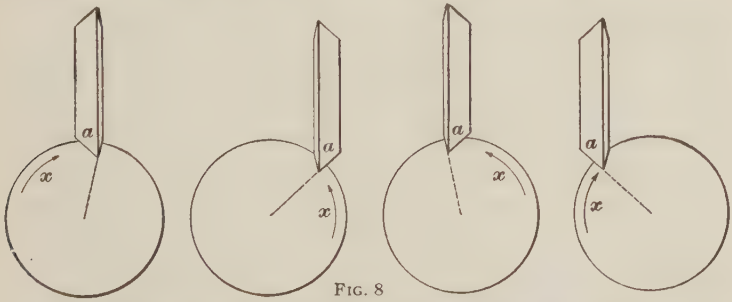


FIG. 8

of the cutter has the greater angle, and the work should revolve toward it, or in the direction of the arrow *x*; this

statement applies to right-hand and left-hand helixes. The direction of rotation that will bring the work toward the greater angle of the cutter can be secured by a proper arrangement of cutter and feed. The object of feeding the work toward the side of the cutter having the greater angle is to make the sides of the groove smooth; smooth sides can be obtained only by rotating the work in the manner stated.

Great care must be taken in all helical work to confine the work so that it can neither slip lengthwise nor turn in the dog or chuck. Should this happen, not only will the work be spoiled, but probably the cutter and arbor also. When the cut has been completed, before running the table back, remove the work from the cutter, or vice versa, so that the cutter will not drag in the groove, and thus mar and score the latter.

SPECIAL MILLING MACHINES

ROTARY PLANER

26. The machine shown in Fig. 9 belongs to a type designed especially for producing flat surfaces by the use of a large side or face milling cutter, and is commonly called a **rotary planer.** The bed *a* has flat ways on top to which the saddle *b* is fitted. The saddle carries the spindle and cutter, which are driven by gearing from the belt pulley *c*. A suitable feed arrangement allows the saddle to be moved along the bed either by hand or automatically; most machines have adjustable tappets by means of which the feed can be stopped at a predetermined point. Practice varies in adjusting the cutter of the rotary planer for the proper depth of cut. In some machines, the spindle and cutter are movable axially to a limited extent, while in others the table can be moved in a direction parallel to the axis of the spindle. Both designs accomplish the same thing and incidentally show that frequently there are a number of different ways of performing the same operation. In the particular machine illustrated, the table is moved by means of a feed-screw operated by the handle *d*. The rotary planer is

also made to be driven by a motor that is mounted on an adjustable circular subbase so that the cutting head can be fed at any required angle to the work. This permits long work, such as bridge beams, to occupy a fixed position, while angular cuts are made on the ends, instead of swinging the outer end of the work to one side to get the angle. This saves room, as well as handling or resetting.

27. Setting of Work.—The work *e*, Fig. 9, is a large bracket, and the surface toward the bed is to be machined so as to be at right angles to the surface that rests on the table. In rotary planers, and also in nearly all milling machines, except those of the vertical type, and in some special machines,

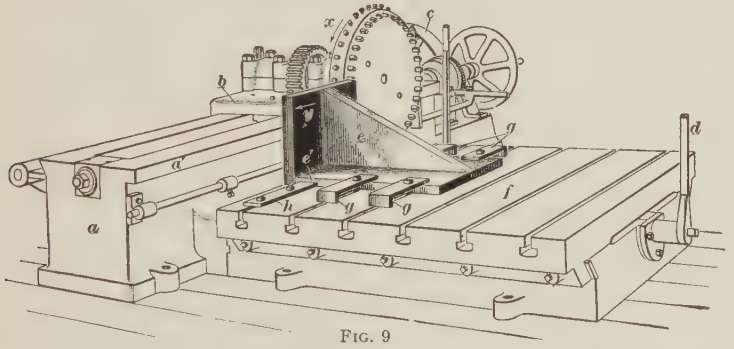


FIG. 9

the axis of the spindle is parallel to the surface of the table *f*; and as a side cutter produces a surface at right angles to the axis of the spindle, it follows from the construction of the machine that if one surface of the bracket *e* rests on the table, the other surface will be machined at right angles to it.

28. If the surface to be machined is to be at right angles to the side surface *e'*, Fig. 9, the work must be fastened in the proper position to accomplish this. If the edge of the table that is toward the bed is parallel to the line of motion of the saddle, a direction in which the main moving part travels, as is usually the case, a try square may be used for lining up the work. The beam of the square is then placed against the edge of the table and the casting is shifted until its side sur-

face e' touches the blade of the square throughout its length. In many cases, the work may be set square by placing the beam of the try square against the edge a' of the bed, which determines the line of motion of the saddle, as it is a part of the ways on which the saddle slides.

29. Work may be set parallel to the line of motion by the aid of inside calipers applied between the edge of the bed and the work, which is adjusted until it calipers the same distance from the bed at both ends. When this cannot be done, the milling cutter itself may be used for testing the setting by having it first in the position shown and measuring the distance between a marked tooth and the work. The saddle is then fed along the bed until the tooth selected for testing is near the left-hand edge of the work; its distance from the work is then measured, and after repeated tests and adjustments, when the two measurements agree, the work is correctly set. The cutter must not be in motion during the process of testing.

30. Clamping of Work.—A job like the bracket shown in Fig. 9 would probably be clamped by using the bolts and clamps g. These clamps may have one end bent to obviate the use of blocking, or they may be straight, in which case they must be blocked up. With the cutter revolving in the direction of the arrow x, the pressure of the cut will tend to shift the work in the direction of the arrow y; for this reason, a stop h is bolted to the table and against the edge e' of the work. The stop is simply a strap having two holes in it; bolts are slipped into a T slot in the table and passed through the holes of the strap, which is clamped by tightening the nuts on the bolts. The strap is held from slipping by friction only; a piece of manila paper should be placed between the table and the strap, as this will greatly increase the resistance to slipping. If the table has holes in it to receive pins, it is better to use stop-pins, as they cannot slip.

VERTICAL MILLING MACHINE

31. The **vertical milling machine** shown in Fig. 10 is one of the many designs in common use. The table *e* is arranged to be fed in two horizontal directions at right angles to each other, but its level is fixed. The spindle *f* is adjustable

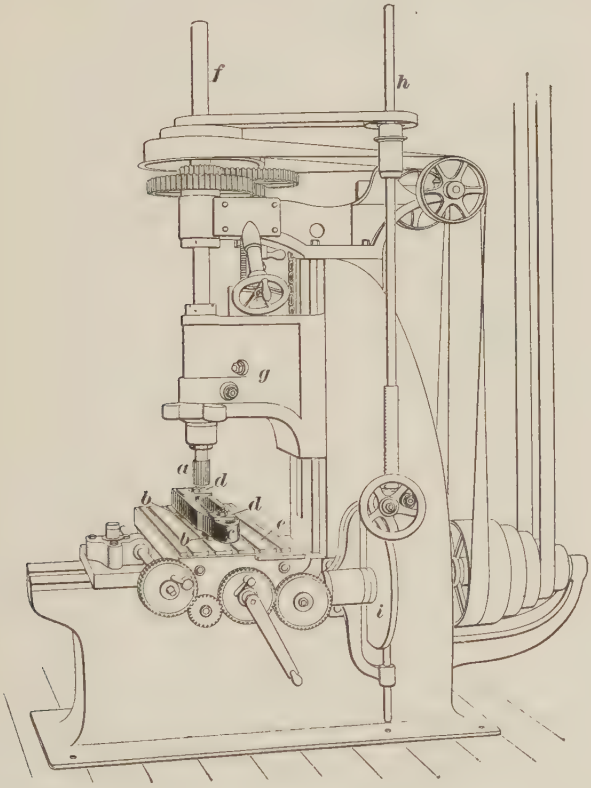


FIG. 10

in a vertical direction, and a good support close to the cutter is furnished by making the head stock *g* adjustable. The table is provided with an automatic feed in both directions; the feed-shaft *h* is driven by belt from a pulley on the spindle *f* and carries a small friction wheel that is in contact with the feed-disk *i* and

rotates it by friction. The friction wheel on the feed-shaft is so fitted that it can be moved along the shaft, and, consequently, its position in regard to the center of the disk *i* may be varied. As the rate at which the feed-disk revolves depends directly on the distance of the friction wheel from the center of the disk, it follows that, by moving the friction wheel to different positions, the rate of feed is varied, and by shifting it past the center of the feed-disk, the feed is reversed.

32. Sometimes the vertical milling machine has a removable bottom bearing for the end of the spindle; this corresponds to the outboard bearing of the horizontal milling machine and serves the same purpose. The vertical milling machine cannot do the work that cannot be done on the horizontal type of machine; it is more convenient, however, for the class of work that requires to be finished with end mills, as the work is in plain sight. The job shown in Fig. 10 might have been done in a horizontal machine by strapping it to an angle plate, but it would not have been in as plain sight.

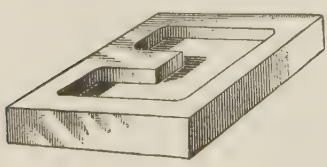


FIG. 11

33. The peculiar advantage of the vertical machine for some work, as far as having the cut in plain sight is concerned, has led to the design of special attachments for converting a horizontal machine temporarily into a vertical-spindle machine. Such attachments are supplied by the makers and are convenient makeshifts for some work, as, for example, the job shown in Fig. 11, that is to have its top surface and all the surfaces of the recess finished by milling. If a vertical-spindle machine is available, it should be chosen for doing the job; in the absence of one, a vertical milling attachment may be used on a horizontal machine. When no such attachment is available for a horizontal machine, the work must be fastened to an angle plate and worked out with an end mill.

34. Holding the Work.—An example of how work may be clamped to the table of a vertical milling machine, when it is required to machine the circumference of the work, is shown in

Fig. 10. The job is the strap for a connecting-rod that is to be milled with a cylindrical end mill *a*. The work *c* is placed on two parallel blocks *b*, that raise its bottom so that the end of the mill may clear the table. Short clamps *d* are placed on top of the strap over the clamping bolts, which have previously been slipped into the T slots of the table. The outside of the strap can easily be finished by milling without changing the setting. After the outside is finished, clamps may be applied from the outside before the inside clamps *d* are removed, which is done when the outside clamps have been tightened. In this way the setting of the work will not be changed and the inside of the strap will be left clear for milling. The straight surfaces of the strap are finished by using the regular feeds; the curved end must, however, be finished by working both feeds simultaneously by hand, cutting to a line previously drawn on the top surface of the strap, which line shows the edges of the work when finished.

35. When the work is held to the table so that it can be machined all around its circumference, it will usually be a rather difficult matter to provide stops that will prevent shifting, and the friction created in clamping must be relied on. As a general rule, whenever it is possible to use positive stops, it is advisable to do so. When friction alone prevents slipping, lighter cuts and lighter feeds must be employed and special care is required in starting the cut.

PLANER-TYPE MILLING MACHINE

36. An example is given in Fig. 12 to show how work may be held on the table of a planer-type milling machine. This machine is of the multispindle type, having two independently adjustable spindles *a* and *b*, which can be used for driving an arbor *c* from both ends, as is done in this case. The work *d* is a side rod for a locomotive, which is to be milled out between the ends to an I section. The cut taken is about $4\frac{1}{2}$ inches wide and $1\frac{3}{16}$ inches deep, and the feed is 2 inches per minute; as a consequence, the pressure of the cutting operation that tends to

slide the work along the table is quite heavy. In this case, movement of the work is prevented by letting it butt against an angle plate *e*, which is bolted to the table at the rear, and which in turn is prevented from shifting by struts that are placed between it and the end of the table; these struts cannot be seen in the illustration. The work is held down on the table by

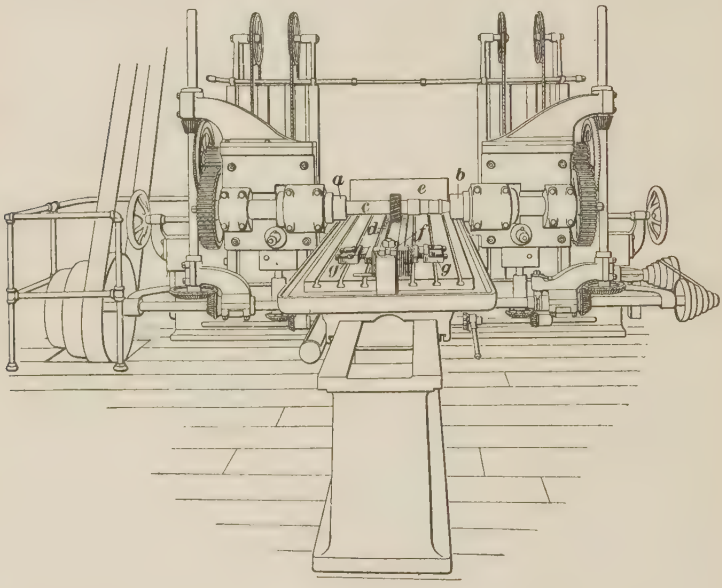


FIG. 12

bolts and clamps placed at each end; the clamp *f* at the front end can be plainly seen. Thrust blocks *g*, each of which has two setscrews, are bolted to the table and are used for adjusting and confining the work sidewise. A double-headed machine, like the one shown, is well adapted for milling heavy work, and especially for finishing two surfaces parallel to each other in one passage of the work past the cutters.

LINCOLN MILLER

37. The special feature of the Lincoln type of milling machine, shown in Fig. 13, is a vertically adjustable horizontal spindle *b* and a corresponding outboard bearing *d*. The table *a* is movable both in line with, and at right angles to, the spindle *b*, and a plain vise *c* is rigidly bolted to the table with its jaws parallel to the axis of the spindle in this case. The Lincoln type of machine is especially adapted for short cuts on work that can be held in a vise, or in any equivalent fixture, and is capable, with proper handling, of doing very accurate work of the class for which it is intended, as the design allows a very compact, rigid, and comparatively inexpensive machine. Machines of this design are largely used in typewriter, sewing-machine, and armory work.

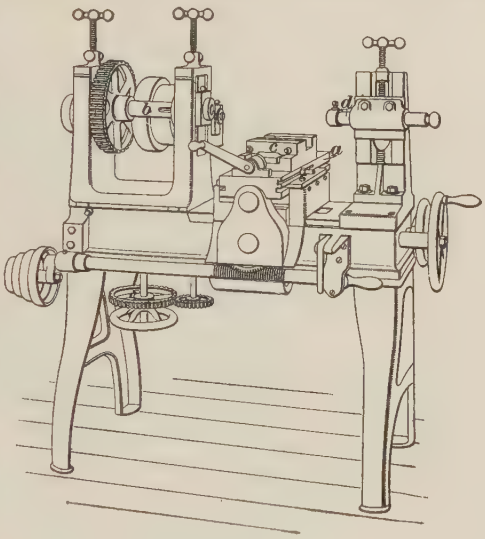


FIG. 13

PROFILING MACHINE

38. In gun, sewing-machine, and similar work, many irregular edges and irregularly outlined slots or recesses must be finished accurately and in large quantities by milling; but automatic feeds cannot be employed. The operation of finishing edges is commonly called *profiling* and the machine used is a **profiling machine,** or *edger*. It is similar to a vertical milling machine, and is shown in Fig. 14. The table *a* runs on a pair of ways on the top of the bed to which it is held

by gibs on the under side. The table is moved endwise by a spur-gear train that engages a rack underneath it. The gear

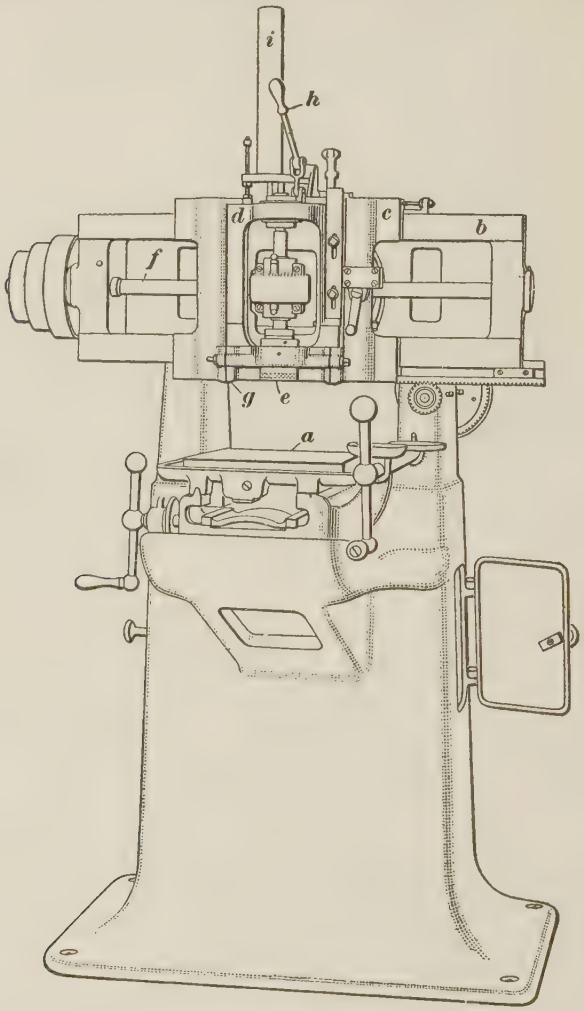


FIG. 14

train is operated by a balanced crank at the left side of the machine. Above the table is a cross-head or rail *b* on which a slide *c* travels horizontally and carries the vertically adjustable

spindle head *d*. The spindle *e* is driven through suitable gearing by the driving shaft *f* and its cone pulley. The slide is moved along the cross-head by the right-hand handle which operates a gear train, the final pinion of which meshes with the feed-rack attached to the slide.

39. The work to be milled on the profiling machine is secured on an attachment that will raise it slightly so that the cutter will not touch the table. A hardened form similar to the required outline is then secured on the other side of the table so that the work and the form have the same relative positions. An end mill is then driven into the spindle and a hardened guide pin of the same size as the cutter is clamped in the slotted holder, *g*, Fig. 14, parallel with the end mill. The head is moved vertically by the hand lever *h*. Tension is maintained on the head by a spring in the spring guard *i* and suitable stops are provided to regulate the vertical movement of the slide. When in operation the former pin in the clamp *g* is held against the form by the compound movement obtained by working the lengthwise and crosswise feeds at the same time, so that as the table feeds lengthwise the tool will be fed crosswise, according to the required profile, and so reproduce the shape of the form on the work held parallel to it. The cutters used are ordinarily end mills and may be tapered, spiral, or of any other required form.

SPLINE MILLING MACHINE

40. A recent form of milling machine is the **spline milling machine,** which is used extensively to mill slots without first drilling or coring the holes. The ordinary range of the machine is to mill straight round-ended slots from $\frac{1}{16}$ to 1 inch in width, to a depth of twice the cutter diameter and of a length of 4 inches between centers. Larger slots may be cut, however, by resetting the piece or by moving it along in the holder. Much of the work of the spline milling machine consists in cutting keyways, tang slots, and similar work, but it may be arranged for curved slots and recesses of various forms by the use of suitable attachments or jigs. As shown in Fig. 15, it consists

of a column *a* having two spindle heads *b* cast solid on the top. A slide *c* between them carries the work table *d* which has an endwise motion at right angles to the cutters *e* held in

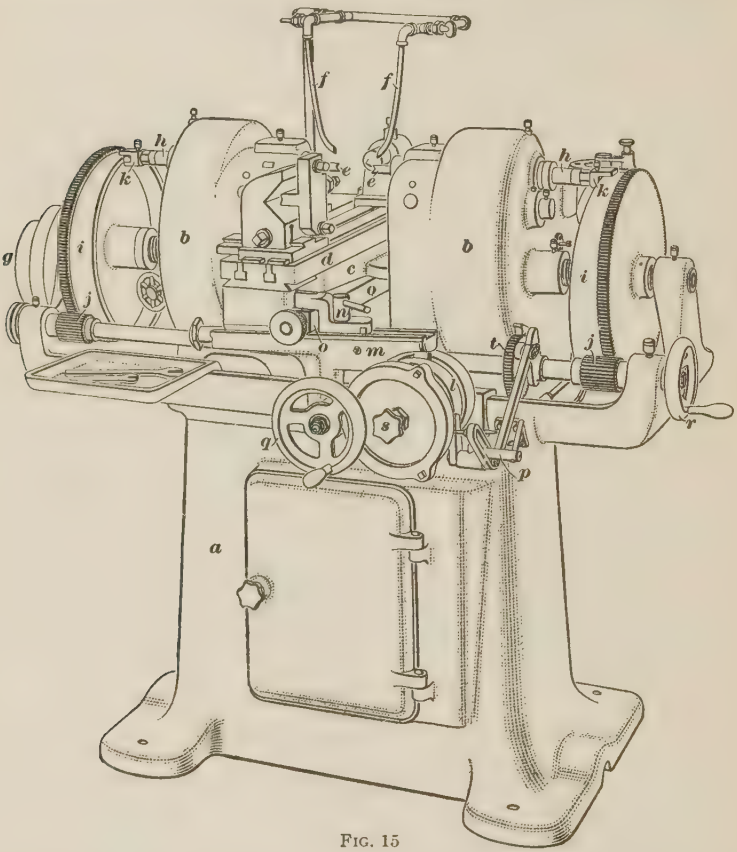


FIG. 15

the spindles. Pipes *f* are provided to lubricate the cutters thoroughly.

41. The spline milling machine is driven by a belt that runs on the pulley *g*, Fig. 15. The spindles *h* are driven by gearing inside the heads and are operated for the depth of cut by the side cams *i*, which are adjustable endwise by spanner nuts on their shafts. The side cams have spur-gear teeth cut on them

and are driven by pinions *j* on the shaft at the front of the machine. The back or outer ends of the spindles are made with forks *k* that engage the rims of the cams and are held in contact with the faces of the cams by weights inside the machine. The spindles can be used together or separately, as required, and rotate in opposite directions so that right-hand cutters only are employed.

42. If a tang slot or other slot is to be milled clear through a piece the cutters are placed in the spindles and the cams are adjusted so that each cutter will be advanced half way through the work and then drawn back to its starting position outside the slot. The two cutters are prevented from meeting at the center, when running in opposite directions, by slipping the driving pinion *j*, Fig. 15, out of mesh with one side cam and turning the cam so that it will complete the cut and return the cutter before the other cutter reaches the center and breaks through the remaining wall of metal to complete the slot.

43. The table is repeatedly moved back and forth past the cutters and is stopped at each end of the groove while the cutters are fed into the work, until the required depth has been reached. The cam then draws the cutter back. The table movement in both directions is provided for by the grooved cam *l*, Fig. 15, which operates the rocker-arm *m*. A **T** slot is cut in the top of the rocker-arm in which the adjustable clamp *n* is secured by a screw and a shoe. A link *o* is held at any required point on the rocker-arm by the clamp and extends through the machine to the other end of the table, to which it is connected by a pin. The length of stroke of the table is determined by the distance that the link is removed from the axis of the rocker-arm.

44. The feed is obtained by a two-lobed groove in the cam *l*, Fig. 15, that operates the table. The cam operates the feed through an adjustable link motion *p* very similar to that of a shaper. The motion given the feed-shaft is then transmitted to the side cams and the cutters by the pinions *j* on the ends of the feed-shaft. The table may be moved by hand by turning the hand wheel *q*; the hand wheel *r* operates the cutter

feed. The feed is thrown in by the knob *s* at the front of the table. The feed that can be taken under different conditions with the two-lipped fish-tail cutter in deep slots in steel is one tooth on the ratchet *t*. Two teeth may be used on steel if the slots are not deep and three teeth on cast iron. If three-lipped or four-lipped cutters are used on steel, the feed can be increased to three or four teeth. These light feeds cause all of the cutting to be done on the end of the cutter, so that true, smooth slots result.

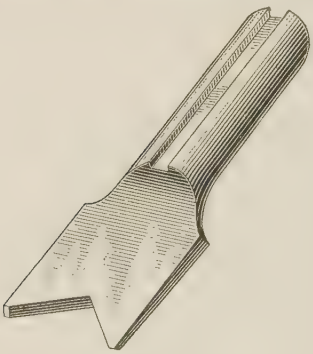


FIG. 16

45. The cutters used on the spline milling machine are called **fish-tail cutters.** They are made with round, splined shanks and the cutting part is flattened. The cutting end is V-shaped and is given clearance on the inner edges so that it may be fed endwise into the work. The central ridge thus formed is cut out as the work is fed endwise past the cutter. The cutter is also made with two, three, or four lips and is right hand. A form of fish-tail cutter is shown in Fig. 16.

COMPARISON OF MILLING MACHINES

46. The universal milling machine is essentially a tool-room machine by reason of the large variety of work that may be done on it with the aid of its attachments. While manufacturing or milling duplicate work in large quantities can be done on a universal machine, a heavy, plain horizontal machine is generally preferable for this work because of its lower cost and greater stiffness. This statement does not imply that a universal machine is not or cannot be made stiff; the fact is that the universal machine, not being intended for the heavier class of milling, is not given the same amount and distribution of metal that is put into a machine especially built for heavy plain milling.

47. The vertical type of machine is to be selected for work that is to be largely done by end mills or side mills; the cut being in plain sight of the operator is probably the most valuable feature of the vertical machine. The Lincoln type of machine was developed in armories, and is especially adapted for milling large quantities of relatively small duplicate work requiring comparatively short cuts. The rotary planer is well adapted for long work that requires the ends to be squared up, and is much used for milling the ends of cast-iron columns and of the different rolled sections used in bridge work and structural ironwork. It is also often employed for surfacing plane surfaces on heavy work; for instance, facing up the segments of built-up fly wheels. Its ordinary use is the production of plane surfaces at right angles to the surface of the table, and it cannot be claimed to be adapted for any other work.

48. The planer type of milling machine is intended for long and heavy cuts with face and plain mills, such as the milling of connecting-rods and side rods for locomotives, the milling of rather wide plane surfaces, beds for machine tools, and similar work. When supplied with index centers, a great deal of the work done in any other horizontal machine can be done in the planer, such as the cutting of gears of various kinds, fluting reamers, etc.

Multispindle machines are best adapted for work having a number of surfaces so situated with respect to one another that several of them can be operated on simultaneously. They are used considerably for heavy work, and then take the place of a planer with a number of heads; in fact, they are intended for the same class of work.

SPECIAL MILLING ATTACHMENTS

49. The range of work for which a milling machine is adapted can be greatly extended by means of special attachments. Those in most common use are: *circular milling attachments*, which are used chiefly in vertical milling machines for the production of about the same kind of work as can be done in a lathe; *vertical milling attachments*, for converting a horizontal

milling machine temporarily into a vertical machine; and *cam-cutting attachments*, for milling cams to a definite shape by the aid of a master cam. A milling attachment is occasionally applied to a planer.

Milling attachments may take almost any conceivable form suitable for the purposes for which they are intended. Few, if any, of these special attachments embody features that call for a description; most of them are simple modifications of those previously enumerated, and have been designed to meet special conditions and requirements.

50. Circular Milling Attachment.—A common form of circular milling attachment is shown in Fig. 17. It consists of a circular table *a* fitted to the base *b* in such a manner that it can be rotated about its axis. For this purpose, a worm-

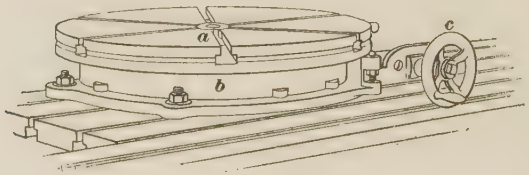


FIG. 17

wheel is placed inside the base, which is attached to the table; a worm, operated by the hand wheel *c*, meshes with the worm-wheel and serves to rotate the table.

The particular form of rotary milling attachment here shown is only intended to be rotated by hand; such attachments are often fitted with an automatic feed, however, that can be adjusted to start and stop at any point.

51. An application of an automatic-feed circular milling attachment is shown in Fig. 18. The work *a* is a worm-wheel blank that is being grooved around its circumference preparatory to cutting the teeth. A formed cutter *b* is used for grooving. This job might be done in the lathe; but the work can be done as well, and much faster, in the milling machine. An automatic feed is of decided advantage for work that is to be milled around its entire circumference, or the greater part of it; in the attach-

ment shown, the shaft *c*, which carries the worm, is automatically rotated by the feed-mechanism. The class of work that may be done with the aid of a circular milling attachment does not differ in general from that which can be done in a lathe. In addition, some circular work can be done for which the lathe is not at all adapted, as, for instance, finishing between the spokes on the inside of the rim of a hand wheel, and the cutting of circular slots closed at both ends.

52. Vertical Milling Attachment.—For many classes of milling, a vertical milling machine is of advantage chiefly

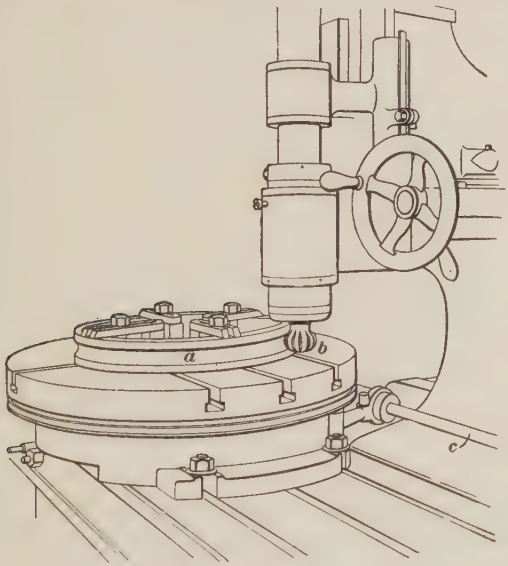


FIG. 18

because the operator is better able to see the cut. In order to obtain this benefit from a horizontal machine, it may be fitted with a suitable device for transforming it, for the time being, into a vertical-spindle machine. While such an attachment cannot be expected to have as large a range as a vertical milling machine, it will greatly extend the range of a horizontal machine, and if properly designed, will allow work to be performed that cannot be done otherwise except by a special

machine. Examples of such work are the cutting of long racks, the cutting of helixes having a very large angle of helix, the sawing off of stock too long to go into the machine in the ordinary way, that is, placed parallel to the spindle, and similar work.

53. One form of vertical milling attachment is shown in Fig. 19. It consists of a frame *a* that carries a central shaft fitted to the hole of the milling spindle and inserted therein. The frame of the attachment is secured to the frame of the machine in such a manner that it can be turned completely about the axis of the horizontal shaft, and can be rigidly clamped in any position. The vertical spindle *b* is carried in bearings

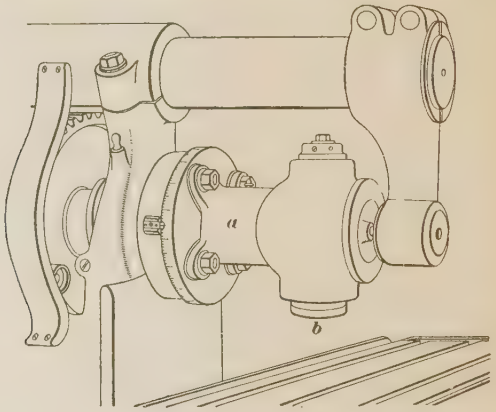


FIG. 19

at the outer end of the frame; as it stands at right angles to the horizontal spindle, it is driven either by bevel gears or by screw gears, in this particular case being driven by the former.

54. The frame of the attachment shown in Fig. 19 is graduated in degrees, and a zero mark placed on the frame of the machine indicates, by its coincidence with the zero of the graduation, when the spindle is vertical. Hence it follows that in this position any end mill will cut a horizontal surface parallel to the line of motion, and any plain mill or formed mill will cut on a side surface parallel to the line of motion. By swiveling the frame of the attachment so that the spindle becomes hori-

zontal, vertical surfaces can be cut with an end mill, and horizontal cuts at right angles to the line of motion of the table can be taken.

55. Vertical Attachment Settings for Cutting Helixes.—A vertical milling-machine attachment of the kind shown can be used for helixes in three ways, two of which adapt it to cases where the table cannot be conveniently swiveled. In the first place, the spindle of the attachment may be rotated about its axis to suit the angle of the helix, that is, until it makes an angle with its vertical position equal to the angle of the helix. A plain mill or formed mill attached to an arbor is then used, and the cut is taken on the *side* of the work.

In the second place, the attachment may be set with its spindle horizontal. In that case, the milling-machine table must be set over to an angle equal to the difference between 90° and the angle of the helix. Using a plain mill, or a formed mill, or a similar cutter attached to an arbor, the cut is then taken on *top* of the work.

In the third place, the attachment may be set with its spindle vertical. It is then used with an end mill, which is applied on *top* of the work for grooving, and on the *side* of the work for plain milling.

As a general rule, the first and the third methods given will allow a greater range of work to be done, and longer helixes to be cut without interference by the frame of the attachment, than is possible with the second method. Since neither the first nor the third method involves a setting over of the milling-machine table, they allow a plain milling machine to be converted into one adapted for helical work.

56. Cam Classification.—The cams in most general use may be classified as *face cams*, *side cams*, and *grooved cams*. A **face cam** is a cam that will cause motion in a direction at right angles to its axis of rotation, as, for instance, the cam shown in Fig. 20 (*a*). A **side cam** is a cam that will cause motion in the direction of its axis, as the cam shown in (*b*). A **grooved cam** may have the groove cut in its face, as the one shown in (*c*); in this case, it will cause motion in the direction of its axis, and

may be called a **grooved side cam,** as it causes a motion similar to that of a side cam. The groove may be cut in the side of the cam, however, as shown in (*d*); in that case, the motion will be similar to that caused by a face cam, and hence it may be called a **grooved face cam.** The term *cylindrical cam* is often applied to cams of the kind shown in (*c*). Cams of the form shown in (*a*) and (*d*) are often called *radial cams*, and cams that cause motion in the direction of their axes, as those shown in (*b*) and (*c*), are sometimes called *axial cams*.

57. Cam-Cutting Attachment.—Nearly all the cam cutting that is done in the milling machine may be classified

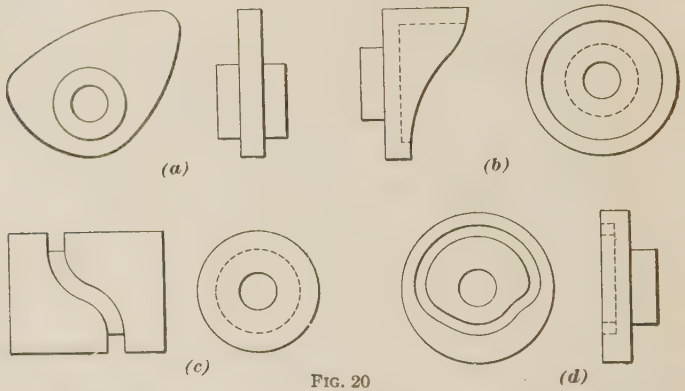


FIG. 20

under the heading of duplicate work; in making a cam, the shape of the working surface is generally determined by a master cam, which serves as a guide, or templet, for guiding the work in relation to the cutter. Fig. 21 shows one form of a cam-cutting attachment in place on a milling machine, and will serve to show the principle involved in the construction of nearly all such attachments. A false table *a* is bolted to the regular milling-machine table; a slide *b* is gibbed to the false table, and is free to slide along it. The slide *b* carries a shaft *c* in a bearing formed in it; this shaft is at right angles to the line of motion of the slide and has a worm-wheel *d* meshing with a worm *e*. The shaft *c* can be rotated by hand or automatically; in the latter case, the pulley *f* is belted to some suitable feed-pulley of the machine.

58. In order that the shaft *c*, Fig. 21, may be driven automatically in any position of the slide, the worm-shaft is splined and is driven by a feather attached to a sleeve that carries the pulley *f*. The shaft *c* is so arranged that it can either be left free to slide in the direction of its axis or can be confined longitudinally; in the latter case, it can only rotate about its axis. The master cam *g* and the work *h* are both fastened to the shaft *c*, and a roller carried by the stationary bracket *i* engages

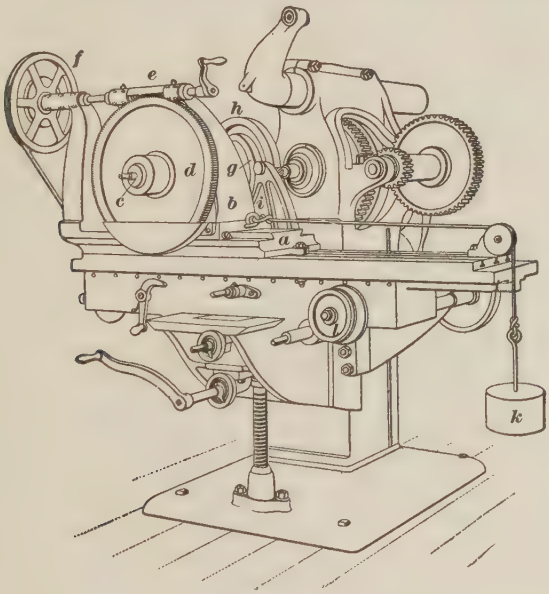


FIG. 21

with the master cam, which is held against the roller by a heavy weight *k* attached to the slide *b*. By turning the master cam the slide is set in motion, and a milling cutter will cut the work to an outline depending on the shape of the master cam. With the attachment in the position shown in the illustration, face cams having their working surface either on the inside or on the outside, and grooved face cams also, can be cut.

59. For milling plain or grooved side cams, a properly made master cam is fastened to the shaft *c*, Fig. 21, which is then

unlocked to allow it to slide. The whole attachment is now turned around until it is at right angles to the position shown in the illustration. The weight *k* is then attached to the shaft *c*, and the roller in the stationary bracket *i* engaging with the side of the master cam, the shaft and the attached work will slide in and out, as induced by the master cam. The automatic feed may be driven, in this case, from the pulley *l*. When cutting side cams in this manner, the slide *b* must be locked to the false table *a*. While this device will *cut* cams from a master cam, it will not *produce* a master cam. This must first be produced in some other manner; in many cases the curves of the master cam are such that it can advantageously be finished to the correct shape by milling, or, perhaps, the greater part can be finished by milling and the rest by filing.

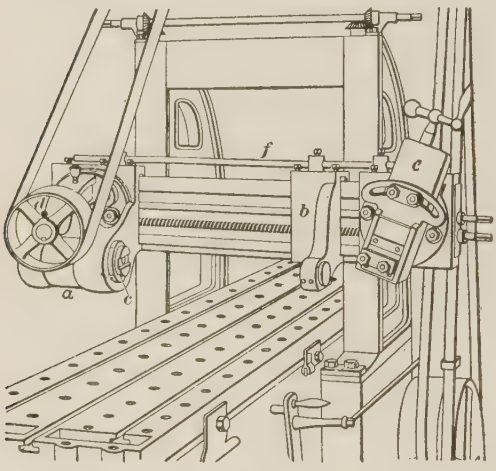


FIG. 22

60. Planer Milling Attachment.—A milling attachment used for converting a planer into a milling machine is shown in Fig. 22. It consists of a head *a* and an outboard bearing *b*, both of which are attached to the regular planer cross-rail. The head *a* carries the spindle *c*, which is bored to take an arbor or the shank of a cutter. The spindle is driven from the pulley *d* by the intervention of suitable gearing. As the regular speed of the planer table is entirely too high to be suitable for the feed, a countershaft must be introduced to lower it, or some equivalent device must be used. The cutter is adjusted for depth of cut by moving the cross-rail up or down the housings; the sidewise position of the cutter is adjusted by

moving the regular planer head *e*, to which the head *a* and outboard bearing *b* are tied by the rod *f*. In the particular design of attachment shown, the head *a* is arranged so that it can be swiveled. This allows angular cuts to be made with a plain mill or a side mill, and greatly extends the range of work that may be done.

61. It is rather doubtful, however, whether such a makeshift as that in Fig. 22 will do as much and as good work as a regular milling machine. On the other hand, it allows work to be done in one setting that cannot be done otherwise without two separate machines, as some parts of the work may be finished by milling, as, for instance, straight grooves having an irregular profile, and the rest of the work, as undercuts, etc., may be finished by planing.

SPECIAL USES OF MILLING MACHINE

62. Special Operations.—In addition to the ordinary uses, many designs of milling machines may be employed occasionally for other work, such as drilling, boring, turning, and graduating. In some cases, the milling machine may be used to advantage for these special operations; as a general rule, however, it will be more economical to use a machine primarily built for the purpose. Thus, while it is possible to do quite a variety of turning in some milling machines, even at the best such a machine will only be a makeshift for a lathe.

63. Drilling.—A milling machine can be used to advantage in index drilling, that is, the drilling of holes properly spaced by the aid of the index head. The work is then mounted on the face plate, or held in the chuck, or attached in some other suitable manner to the index head, which is placed so that its spindle faces the milling-machine spindle. The drill used is held in a chuck driven into the milling-machine spindle; it should project as little from the chuck as circumstances permit. In some cases, it is possible to utilize the outboard bearing for steadying a long drill by placing a steadying bushing that closely fits the drill in the bearing and adjusting the latter so that it will be close to the work.

64. When accurate spacing is required, the drill should be followed by a reamer made in the general form of a chucking reamer; but it should have about twice the clearance to prevent it, as much as possible, from following a hole that has been drilled out of line. The feeding, in drilling, is done by moving the table and the attached work toward the drill. When all the holes are to be drilled to the same depth, the stop may be used, if one is provided; otherwise, the graduated dial may be employed to indicate when the correct depth has been reached. In making drill jigs, the milling machine may occasionally be employed to advantage for spacing the holes correctly, using the graduated dials to indicate the spacing. The accuracy with which the holes will then be located will depend primarily on the accuracy of lead of the different feed-screws, and also on the skill used in reaming or boring the holes.

65. **Boring.**—A cored or drilled hole may be finished by boring with a regular boring bar and cutter, using the outboard bearing for supporting the bar, in case it is rather long. The methods of holding the work and lining it up, and, also, of taking the cut, are exactly the same as are used in a regular boring mill except that the feeding may have to be done by hand, if the milling machine has no automatic feed in the direction of the spindle. In a machine in which the table can be swiveled so that its line of motion will be in line with the milling-machine spindle, quite a long hole can be finished by boring, and, in that case, the regular automatic feed can generally be used.

66. **Turning.**—Occasionally it will be found desirable to do some turning in the milling machine. In that case, the turning tool is held in the vise and the work is driven by the milling-machine spindle; the machine is then used as if it were a lathe.

67. **Graduating.**—A universal milling machine having graduated dials reading to .001 inch can be used for a good many jobs of graduating, either on straight or curved surfaces. For graduating straight surfaces, as rules, for instance, the divisions are obtained by means of the feed-screws, and the

length of the graduation lines by means of one of the other feed-screws at right angles to the first A good way to proceed is to cut all the longest graduation lines first, using a stop to insure that all are of the same length, then to cut the next shorter lines to the reset stop, and so on.

68. The two general methods of marking graduation lines on work are the *cutting method* and the *squeezing method.* For coarse graduations, a double-angle cutter may be employed; for fine graduation lines a single-pointed tool is clamped to the spindle and used as a planer tool, the work being traversed beneath it. The spindle, in that case, is prevented from turning by being blocked in any suitable manner. The objection to cutting graduation lines by planing is that the cut is comparatively rough on account of the rapid dulling of the tool due to the dragging of the cutting point during what may be called the return stroke. This dragging can be overcome by placing the tool in a clapper as used on a planer, thus allowing the tool to swing away from the work, and preserving the point longer.

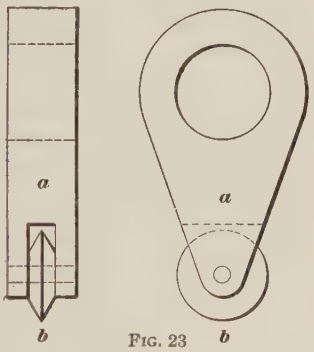


FIG. 23

69. For the ordinary graduating work that a machinist may be called upon to do, the most satisfactory results can be obtained by the squeezing method. Fig. 23 shows a good form of tool for this purpose. It consists of a holder *a* bored to fit the arbor of the milling machine spindle. The sides of the holder are faced parallel with each other and square with the hole. The end is forked and carries the sharp-edged hardened marking wheel *b*, which is free to turn on a pin, but is confined sidewise by the forks of the holder. The marking wheel should be ground perfectly true after hardening and the angle included between the two faces may vary from 60° to 90°. With the smaller angle, finer graduation lines can be obtained; but a wheel with the larger angle will last longer.

70. In use, the holder shown in Fig. 23 is clamped on the arbor as if it were a cutter and the spindle is then blocked. The work having been adjusted so that the surface to be graduated is slightly above the edge of the wheel, it is traversed beneath the latter, which rolls or squeezes in a graduation line that has slightly raised edges, which may be removed afterwards by grinding or filing. Fig. 24 is a greatly enlarged cross-section of a graduation mark formed by squeezing, and shows the raising of the edges. In favor of this method of graduating it may be said that the lines will be smooth, and that a tool will last a very long time with reasonable use.

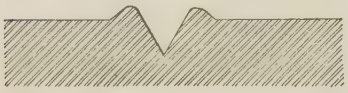


FIG. 24

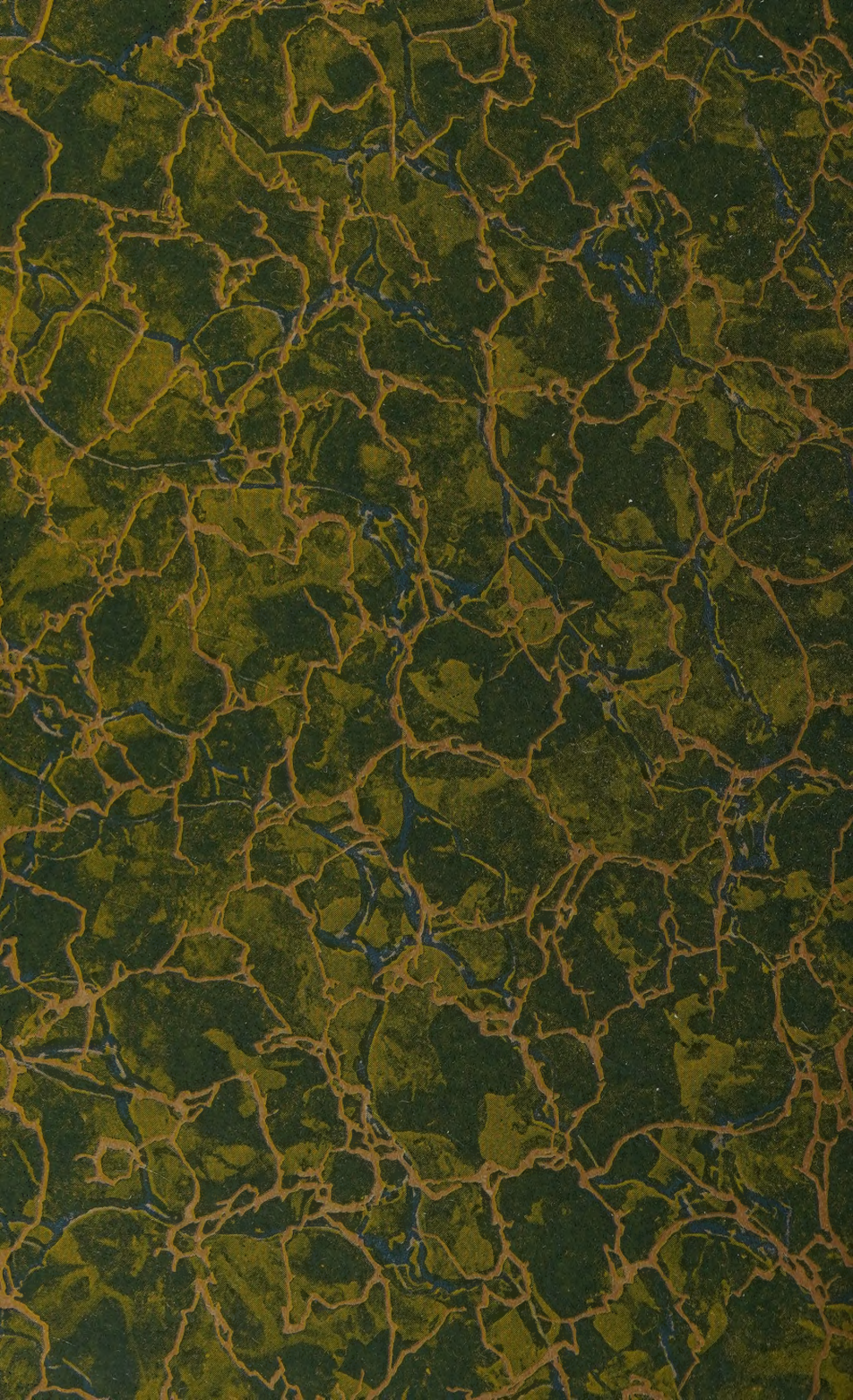
71. The index head affords a ready means of dividing circular dials of various kinds into even divisions. The stop to the table may be used for regulating the length of the graduation lines; when no stop is available, the reading of the dial on the feed-screw will indicate where to stop feeding in order to make all lines of each set equal in length.

LIMITATIONS AND ERRORS

72. The limits within which work can be milled to a given size largely depend on the construction and condition of the machine, the character of the workmanship required, and the nature of the work. With a high-grade machine in first-class condition, and using sharp cutters on work that is rigidly held, many jobs can readily be milled within a very small limit of variation, as, for example, .001 inch. In fact, on many classes of duplicate work done in large quantities, all fitting can be done away with entirely, as it is practicable to mill the work close enough for a fair fit. With a springy machine in poor condition, and dull cutters, such results cannot be obtained, and the work done by them will usually call for considerable hand fitting, not only on account of the greater variation in the size, but also because of the poor quality of the surfaces produced under such conditions.

73. The limit within which work should be milled to a given size cannot be definitely stated, as it naturally depends on the purpose of the work. For comparatively rough work, as milling nuts, bolt-heads, the squares on the ends of taps and reamers, etc., a limit of .004 inch may usually be considered as allowable. Work that is milled only for finish can often vary considerably from its true size; the amount allowable must obviously be determined on the merits of each case. Parts of sewing machines, typewriters, firearms, and similar small work are usually finished within a limit of .002 inch, although some parts require to be, and can be, finished within a smaller limit.

74. When milling large work, or finishing a rather wide surface with a plain mill, it is not always possible to obtain as close an approach to a plane surface as the planer tool with its single cutting edge will produce. One reason for this is a lack of stiffness of the machine used; another reason is that, with a milling cutter, the pressure on the work during the cutting operation is many times greater than in the case of the planer tool; consequently, there will be more springing of the tool and the work. Furthermore, when a plain cutter is beginning to take a chip while the work is fed against the cutter, the pressure is at first in line with the surface of the work, or nearly so. Now, as the cutting tooth advances upwards, the direction of the pressure changes, and, being upwards, tends to lift the work from its fastenings. This change in the direction of the pressure is naturally most marked in deep cuts, and if the work yields to a sensible extent, an uneven surface will result.

75. In a planer, shaper, or slotter, the direction of the pressure never changes, and as its intensity is much less than with a milling machine, it follows that as far as large plane surfaces are concerned, the machine tools first mentioned can, in general, be better relied on to produce them. As a matter of course, with a very stiff machine especially designed for surface milling, and with work so stiff that deflection will be so small as to be insensible, a very close approach to a plane surface can be obtained by milling; in general, however, it will

be found that the planer has slightly the advantage. For this reason, it is customary in some places to rough out the surface of heavy work on some suitable form of milling machine, and then to transfer the work to a planer, where it is finished by planing. This course will, in many cases, be more economical than planing the whole job, as with a properly designed and handled milling machine the roughing out can usually be done at a fraction of the cost of planing.